THE UNIVERSITY OF ALBERTA

SOME ASPECTS OF THE RELATIONSHIPS BETWEEN RESTING, EXERCISE, AND RECOVERY HEART-RATES AND PHYSICAL FITNESS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Some Aspects of the Relationships Between Resting, Exercise, and Recovery Heart-Rates and Physical Fitness", submitted by Anthony William Sedgwick in partial fulfilment of the requirements for the Degree of Master of Arts.

ABSTRACT

The purpose of this study was to compare the extent to which resting, exercise and recovery heart-rates are related to physical fitness defined as the ability to perform prolonged heavy work.

The criterion measures of fitness were time-run in the Johnson, Brouha, and Darling test, Maximal Oxygen Intake obtained from the Astrand Bicycle Ergometer Test, work done to reach Maximal Oxygen Intake and the Johnson, Brouha, and Darling Fitness Index. Some aspects of the interrelationships of the fitness criteria were studies as subsidiary problems.

Data were analysed for 40 subjects, aged 17 to 35, comprising University students and staff, and soldiers.

Mean values and standard derivations were computed for all variables, and each variable was correlated with all other variables.

The mean values obtained revealed that subjects classified as 'fit' or 'less fit' according to whether or not they completed five minutes running in the Johnson, Brouha, and Darling Test, differed significantly in all the measures of fitness used, in exercise heart-rates, for light, moderate and heavy work loads, and in recovery heart-rates counted shortly after light and moderate work. No significant differences were found between recovery heart-rates counted shortly after intense work leading to maximal or near maximal heart-

rates, maximal heart-rate, and rate of heart-rate recovery during the first minute of the recovery period after light, moderate, and heavy work.

With respect to the results obtained the principal conclusions reached were:

1. The relationship between exercise heart-rate (in stationary cycling against fixed submaximal loads with work periods of six minutes duration) and fitness tends to increase with work load, and to some extent with duration of work for a given work load.
2. The relationship between recovery heart-rate (associated with stationary cycling as described above) and fitness tends to increase with work load and declines as duration of recovery extends.
3. Maximal heart-rate, recovery heart-rate following work leading to maximal heart-rate, and rate of heart-rate recovery following light, moderate, and heavy work, are poorly correlated with fitness.
4. Resting heart-rate is significantly correlated with certain fitness criteria, but for a given criterion is less closely correlated with fitness than exercise and recovery heart-rates associated with submaximal work.
5. Exercise heart-rate in stationary cycling against fixed submaximal loads, and recovery heart-rates counted shortly after such work are significantly correlated with certain criteria of fitness to a degree which does not differ significantly.

6. Maximal Oxygen Intake is significantly correlated with time-run in work which exhausts all subjects in less than five minutes.
7. Maximal Oxygen Intake is significantly correlated with work done to reach Maximal Oxygen Intake when both measures are obtained from the same work task.
8. Work done to reach Maximal Oxygen Intake is significantly correlated with time-run in work which exhausts all subjects in less than five minutes.

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CHAPTER I

STATEMENT OF THE PROBLEM

Introduction

This study is an attempt to assess the value of heart-rate as an index of physical fitness, and to compare the values of heart-rates counted at rest, during exercise, and after exercise.

Physical fitness is defined here as the ability to perform prolonged heavy work. This definition embraces all types of work which demand the action of large muscle groups, contracting with sub-maximal force for relatively long periods of time.

There are many criteria used in measuring physical fitness, which can usually be classified under one of three headings - (a) a work test, (b) a test of physiological capacity, and (c) a test of physiological cost in relation to work performed.

The first type of test, the work test, is typified in the time-run tests used by Taylor (73), and Nagle and Bedecki (65). According to Taylor (73), the only defensible criterion of fitness for prolonged heavy work is the amount of work an individual can do. Tests of this type are tests of endurance 'par excellence', culminating at an end-point which is theoretically complete exhaustion. Clearly psychological factors, such as mood and motivation, influence test results. It seems appropriate to refer to this type of test as 'direct'. The criterion of 'direct' tests of fitness is that the more work

an individual can do, the fitter he is.

Tests of physiological capacity, such as vital capacity, total blood volume, and maximal oxygen intake may be described as 'indirect' tests of physical fitness. Rather than serving as measures of work per se, they measure physiological capacity in functions thought to be crucial to work ability. The greater the capacity the fitter one is, and theoretically, the greater the amount of work one should be able to perform other things being equal.

One of the most widely used tests seems to be that of maximal oxygen intake. It is generally agreed that this variable is closely related to fitness (13, 46, 70, 73) and some authors (31, 44) favour it as the best measure of fitness available. It is thought by Taylor and Christensen (74) to be independent of the subjective factor, provided that subjects are able to work to a reasonably high level.

Indirect tests provide less complete measures of fitness than actual work tests, insofar as they measure physiological potential in isolation from the integrated psycho-physiological complex of the working organism. This does not detract from their value, but indicates that they test different phenomena from work tests. The fact that they measure isolated factors makes them useful in studying the relative contributions of different aspects of the individual to work ability.

Tests of the third type (termed 'ratio' tests here) in which an estimate of physiological cost is related to the work

performed, vary considerably. They are usually based on the principle that the fitter man can do a fixed amount of work with a lesser depletion of his physiological capacities, or that in achieving a given level of energy expenditure or physiological 'state' he can do more work. These tests are usually submaximal and use heart-rate as the index of work cost. Typical examples are the Astrand-Ryhming predicted test of maximal oxygen intake (14), the Sjöstrand test (72), and the Balke-Ware test (15). It is interesting to note that the first two of these three tests are designed to predict direct and indirect fitness respectively. From the ratio of heart-rate to work-load the Sjöstrand test predicts the actual work an individual could perform if he were pushed closer to his maximal effort. From the ratio of heart-rate to work load the Astrand-Ryhming test predicts maximal oxygen intake. These tests were designed to save the elaborate experimental procedures and/or the great effort required from subjects in direct measurement of work capacity and maximal oxygen intake. A further example of this kind of test is the Johnson, Brouha, and Darling test of physical fitness (49). In this test an index is derived from time-run and an estimate of the post-exercise heart-rate recovery curve. For subjects who complete five minutes of running this is a submaximal test, and fitness is differentiated by post-exercise heart-rate. For subjects running less than five minutes, it is a maximal test and subjects are chiefly differentiated by time-run. Further discrimination is achieved in those running the same length of time but less than five minutes by heart-rate recovery.

Among the many variables used in the testing of fitness, heart-rate has probably been the most widely used. Abrahams (1) pointed out that the relation of heart-rate to exercise is so obvious and its investigation so simple, that it must make the strongest appeal as a test of efficiency. There seems to be widespread agreement that the fit are distinguished from the unfit by a lower resting heart-rate, a smaller increase for a given amount of submaximal work, an earlier achievement and longer maintenance of a steady-state, a longer time to reach maximal heart-rate, and a quicker recovery following exercise. The principle thought to underly the difference between fit and unfit with respect to heart-rate was described by Assmussen and Nielsen (6) who explained that on account of a large stroke-volume the trained heart is able to attain a larger minute volume at a lower heart-rate than the untrained. Frick et al (41:145), referring to the effects of training stated: "It is obvious that the training had evoked a clear increment in the stroke-volume permitting the total blood flow of pre-training magnitude to be achieved with a slower heart-rate both at rest and during exercise."

However, not all physiologists are agreed about the value of heart-rate as a test of fitness (37), and there is controversy as to which counts, taken at rest, during or after exercise, best indicate fitness. Abrahams (1) suggested that acceleration of heart-rate due to exercise is of less consequence than recovery heart-rate. Astrand (13) and Darling (32) have expressed the view that recovery heart-rate is a suitable measure of changes of fitness in one individual, but is of limited use in different-

iating between individuals. Karvonen (51) has suggested that heart-rate in rest, exercise, and recovery may reflect mechanisms of the cardio-respiratory system which are largely independent. The most serious disadvantage of heart-rate as a fitness measure is that it is readily influenced by factors other than work intensity. These include ambient temperature, humidity, time of day, digestive functions, fatigue, and emotion (76). If these factors influence heart-rate in a manner unrelated to the effect of work, then clearly the reliability and validity of heart-rate as a fitness index will suffer. In order to evaluate heart-rate strict control of environmental conditions is required.

It is logical that heart-rate should be related more closely to some fitness criteria than others. Being a physiological variable one would expect it to reflect maximal oxygen intake more closely than a work variable such as time-run, where factors other than physiological influence performance. Again, since heart-rate is an aspect of the cardio-respiratory system one would expect it to reflect work which is mainly aerobic rather than work which is also anaerobic to a high degree. With these possibilities in mind the present study relates heart-rate to a variety of fitness criteria, corresponding to the classification described above. The criteria are briefly as follows:

(a) A <u>direct</u> criterion in terms of the ability to continue work.

(b) An <u>indirect</u> criterion in terms of maximal oxygen intake.

(c) A ratio criterion in terms of time-run and recovery heart-rate.

(d) A second ratio criterion in terms of the amount of work done in reaching maximal oxygen intake.

The Problem and Subsidiary Problems. The main problem in this study is to compare the relationship between heart-rates counted at rest and during and after exercise, and physical fitness according to the criteria described above. Heart-rates counted during and after exercise are associated with work loads classified as light, moderate, and heavy. A second problem is to determine which fitness tests, if any, are most closely related to heart-rate. To interpret the relationships between heart-rate and fitness it is necessary also to examine the relationships between the different criterion measures of fitness. Some of these relationships have intrinsic interest, apart from the light they cast upon the significance of heart-rate. Three in particular are of importance, and constitute subsidiary problems.

(a) The relationship between maximal oxygen intake (indirect fitness criterion) and time-run (direct fitness criterion). This relationship tests the degree to which aerobic capacity is involved in endurance as it is tested in the Johnson, Brouha, and Darling test.

(b) The relationship between maximal oxygen intake and the work done in reaching it. Theoretically an individual with greater maximal oxygen intake

should perform more work than one with a lesser capacity. This relationship is a test of the validity of maximal oxygen intake as an index of the ability to perform work which is chiefly aerobic.

(c) The relationship between time-run and work done to reach maximal oxygen intake. The tests involved in this relationship, that is the Johnson-Brouha and Darling test (49), and the Astrand test of maximal oxygen intake (12), are quite different. The former is a test of endurance taken to exhaustion; work load is constant and is automatically adjusted to body-weight; it is of relatively short duration (2 to 5 minutes) and high intensity; it is a running test; it involves considerable determination. The latter, theoretically, is not a maximal work test and therefore not strictly a test of endurance; work load is progressively increased in the same manner for all subjects irrespective of body-weight; it is of relatively long duration (12 to 26 minutes) and low intensity; it is a cycling test; it is theoretically independent of psychological factors in healthy subjects of the type used.

Common to both tests are the use of large muscle groups and the heavy load placed on the cardio-respiratory system. The statistical relationship between tests may show approximately to what extent aerobic work is a common factor.

Justification of the Study. The validity of heart-rate as an index of fitness is still controversial, and this is the main justification for this study. Apart from this the literature contains few systematic studies which compare the predictive value of heart-rates counted in rest, exercise, and recovery situations. The problems studied are of practical as well as theoretical interest. In regulating the training process, whether in the area of athletic endeavour, industry, or military action, tests of fitness are useful. As mentioned before, heart-rate commends itself because of its simplicity, and is already in common use in track, swimming, canoeing, and rowing training, and forms the basis of interval and tempo training. It is therefore important to validate heart-rate measurements as a fitness index by correlating it with other indices which are widely used and evidently well accepted. The subsidiary problems are justified insofar as they may clarify interrelationships between different criteria of fitness.

Assumptions. The following two assumptions underly this study:

(a) Aerobic capacity is the chief physiological factor limiting the types of work performed in this experiment.

(b) The mechanical efficiency of stationary cycling and treadmill running is high for well and poorly conditioned subjects alike, so that differences in performance may be accredited to cardio-respiratory function and/or endurance rather than to different levels of skill.

Definition of Terms

Physical Fitness. The ability to perform prolonged heavy work involving the action of large muscle groups contracting with submaximal force for relatively long periods of time.

Time-Run. The time run in seconds by subjects not completing five-minutes running in the Johnson, Brouha and Darling fitness test.

Maximal Oxygen Intake. The maximal amount of oxygen an individual is capable of utilizing while performing a prescribed type of muscular exercise.

Work done to Achieve Maximal Oxygen Intake. The amount of work done, in Kilopond metres, by an individual up to the point where the criterion of maximal oxygen intake is reached.

Kilopond Metre (kpm.). One kilopond metre is the force acting on the mass of one kilogram (kg.) at the normal acceleration of gravity.

Light Work. Six minutes of cycling, at a load of 600 kpm. per minute in the Astrand test.

Moderate Work. Six minutes of cycling, at a load of 900 kpm. per minute in the Astrand test.

Heavy Work. Six minutes of cycling, at a load of 1200 kpm. per minute in the Astrand test.

Heavy Work (Running). Two minutes of treadmill running at 7 m.p.h. and 8.6% grade.

Submaximal Work. A work load which is of standardised duration and is completed by all subjects as in light moderate, and heavy work (cycling and running) defined above.

Maximal Work. This term is synonymous with time-run. In this study maximal work was performed by only those subjects (N = 22) not able to complete 5 minutes running in the Johnson, Brouha, and Darling test.

Resting Heart-Rate. Heart-rate measured by palpation, following fifteen to thirty minutes rest in a recumbent position.

Exercise Heart-Rate*. Heart-rate, counted at intervals during work.

Maximal Heart-Rate. The highest heart-rate achieved by an individual during the Johnson, Brouha, and Darling test.

Recovery Heart-Rate. Heart-rate counted at intervals during the four minute period immediately following exercise.

Rate of Heart-Rate Recovery. The difference between final exercise heart-rate and recovery heart-rate one minute after exercise. It is a measure of change, or decelaration of heart rate and is not to be confused with recovery heart-rate per se, which is a measure of instantaneous heart-rate.

Steady State Heart-Rate. The tendency for heart-rate to remain the same (± 2 b.p.m.) during sub-maximal exercise.

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* All heart-rates except resting were calculated from E.C.G. recordings as described in Chapter III.

CHAPTER II

REVIEW OF THE LITERATURE

The literature relating to heart-rate is extensive, and this review is far from exhaustive. References are intended to illustrate the specific ways in which heart-rate measurements have been used, and some discussion of background theory is included. For convenience the review is divided into sections for resting exercise and recovery heart-rates. Major considerations are as follows:

1. The evidence relating to heart-rate differences between well and poorly conditioned subjects, and changes in heart-rate with training.

2. The degree to which different counts of heart-rate are affected by environmental conditions other than work.

3. The range of differences between subjects provided by different counts of heart-rate.

4. The reliability and validity of heart-rate measurements.

Resting Heart-Rate. It is not always clear in the literature as to how resting heart-rate is measured. It is usually counted following period of seated or lying rest of ten to thirty minutes duration. In this review the term refers to basal heart-rate, taken in a resting state either following sleep or after rest in a lying position.

Cotton (30) reviewed evidence showing that athletes have lower basal heart-rates than non-athletes, and reported his own data showing that athletes of different calibre in the same event are differentiated by basal heart-rate. Champion swimmers had basal heart-rates 7 b.p.m. slower than merely highly trained swimmers. He further demonstrated that among his subjects those with a greater athletic history had lower basal and resting heart-rates than persons with a lesser athletic history. Bramwell (22) found Olympic marathon runners to have resting rates 8 b.p.m. slower than sprinters. Henderson et al (43) found a resting heart-rate range of 45 - 78 b.p.m. for athletes as against 74 - 88 b.p.m. for non-athletes. With regard to the effects of training Astrand (13) suggested that resting heart-rate decreases, and this was demonstrated by Karvonen (52) and Knehr et al (53). Frick et al (41) and Cogswell et al (29) found no decrease with training.

It has been suggested (4, 49) that the differences between individuals in physiologic functions measured at rest in relation to low work rates are too small and overlapping to provide a reliable index of fitness. This phenomenon appears to be one of the chief limitations of resting heart-rate as a fitness index.

A further limitation is the facility with which resting heart-rate is affected by environmental factors not directly associated with exercise (56, 76). It is clear that even if these effects are small, they are likely to obliterate the already small differences between the resting heart-rates of individuals

which are supposedly due to fitness. These factors are likely to decrease the reliability of reating heart-rate, and its validity as a test of fitness.

Rozenblat (71) and Brouha and Heath (24) reported no satisfactory relationship between resting heart-rate and performance. Taylor (73) claimed that the literature consistently demonstrated no useful relationship between fitness and resting heart-rate. His view was supported by Cook and Pembrey (29) and Linde (57).

From a practical viewpoint resting heart-rate is easy to record. However its sensitivity to environmental influences mitigates against its predictive value since there are obvious difficulties in providing conditions which adequately control these influences.

A further factor limiting its usefulness is that it seems to change little if any with age, at least after about 25 years of age, (5, 36, 69). Since fitness by the criteria used in the present study is known to decrease with age, then the relationship between resting heart-rate and fitness seems to be of minor importance.

Although absolute resting heart-rate enjoys little favour, some authors see fit to include it in fitness indices in conjunction with other counts of heart-rate. Examples are found in the Modified-Step-Test (45), the Tuttle Pulse Ratio (77) and in the calculation of cardiac cost according to Brouha (23). Astrand (13) discourages such "mixing" of heart-rates.

Exercise Heart-Rate. Tests of physical fitness using heart-rate during exercise have been widely used (2, 15, 17, 81) and usually employ heart-rate in one of two ways: (a) the amount of work which can be performed for a certain heart-rate, typified in the "physical work capacity" test used by Adams *et al* (2) and the "optimal work capacity" test described by Balke and Ware (15), and, (b) the heart-rate response to a given amount of work. These tests apply two well established principles:

1. That well conditioned subjects have a lower heart-rate at various levels of work (47, 76) and that training results in a decrease in heart-rate for a given work load, or an increase in the work required to produce a given heart-rate (19, 41, 50).
2. That a linear relationship exists between heart-rate, work load, oxygen consumption (energy expenditure) through sub-maximal work and up to work resulting in heart-rates as high as 180 b.p.m. (13, 14, 36, 59).

Taylor (73) expressed the relationship between heart-rate and work load in terms of the correlation coefficient, finding correlations of .969 and .955 between work load and heart-rate for two subjects in an extensive series of tests with loads varying between 636 kgm/min. and 1191 kgm/min. Astrand and Ryhming (14) developed a system, based on the linear relationship between work load, heart-rate, and oxygen consumption, in which maximal oxygen intake is predicted from heart-rate response to a known amount of work. Astrand (9) emphasized that this system gives

only a rough estimate of maximal oxygen consumption. Sjöstrand's test of physical work capacity (72) is premised on the linear relationship between heart-rate and work-load.

Taylor et al (76) in a recent review of fitness tests concluded that if certain conditions are controlled tests using heart-rate in submaximal work provide an indirect measure of aerobic capacity and a measure of work capacity. The need for control of testing conditions was emphasized. He suggested that heart-rate curves during work may be deflected by such factors as meals before the test, fatigue, mechanical efficiency, humidity, temperature, and emotion. Temperature and emotion seem to be of particular importance. According to Dill (35) when temperature is not closely controlled heart-rate is notable for its lack of constancy while other variables associated with work and fitness (e.g. oxygen uptake) are notable for their constancy. Le Blanc (56) referred the effect of temperature and Horvath (47) reviewed similar evidence. Taylor et al (76) suggested that temperatures between 60 - 65° F allow discrimination between individual levels of fitness (in terms of heart-rate) with minimized effects of temperature.

With reference to emotional effects on heart-rate Taylor et al (76), suggested that physiologists using submaximal work tests make the assumption that the stress of work overrides the effects of emotion on the behaviour of the work and/or recovery pulse. He took the view that work may minimize such effects, but gave an example of a dramatic increase in heart-rate during a

treadmill run as a result of a subject stumbling. He also cited evidence showing that maximal heart-rate is not affected by emotion. Astrand et al (10) found the relationship between heart-rate and work to be unaffected by emotion and stated that heart-rate and oxygen consumption are regulated within narrow limits determined by the work output and the fitness of the subject and are apparently highly resistant to changes in mental state. These conclusions were partly based on an experimental situation in which (a) the source of emotional stress was the prior knowledge of the duration of the work test, and (b) there was only one subject who, moreover, was trained and experienced in such tests. The source of emotion does not appear to have been great, particularly in the case of a subject highly familiar with endurance tests. Reference was also made to experience with Olympic skiers. Their heart-rates were not significantly affected by the emotion (inferred) associated with training and competition. Rozenblat (71) presented contrary evidence, finding that basket-ball players during training, when the effort was moderate, maintained heart-rates of between 180 and 198 b.p.m. for long periods, and accredited this high level to emotional influences.

It would seem however, that in certain controlled conditions heart-rate is a remarkably stable variable. Dill (34) showed that heart-rate in controlled temperature and humidity conditions had a probable error of not more than 2 or 3 b.p.m. Taylor (73) found a test-retest reliability for heart-rate in submaximal work of 0.78 when the range for his subjects was

108 - 153 b.p.m. When the heart-rate range increased from 188 to 212 b.p.m. the reliability for 31 subjects increased to 0.81.

Borg and Dahlstrom (21) gave figures relating to the reliability of heart-rate during work. At a work level of 900 kpm. on the cycle ergometer the correlations between heart-rate after 4 minutes and 6 minutes of work, on two separate testing occasions were 0.97 and 0.98 respectively. At 600 kpm. the corresponding figures were 0.90 and 0.94. At the same level after 2 and 4 minutes of work correlations were 0.88 and 0.91. This, together with Taylor's data (73), suggests that the higher the heart-rate the greater the reliability of individual differences. This trend may reflect the 'tacit assumption' previously stated that work tends to overcome the effects of emotion on heart-rate variability. Taylor's (73:204) comment on variation in response to tests is worth quoting: Referring to intraindividual variability he said that it is,

> ".... the greatest source of test unreliability because in the usual situation it serves only to detract from the differentiating effectiveness of the test. Such intra-individual variation unaccompanied by any tangible change in the fitness of the individual must at the present time be considered an obstacle to the reliable determination of the prevailing fitness of the individual. Most of the measures, which are of low reliability in the submaximal exercise, are improved when taken during maximal exercise."

Just as a higher level work seems to increase reliability, it seems also to increase the arithmetic differences between fit and unfit, that is it provides a large scale. This tendency is

demonstrated in Figure 1, which shows data collected at the University of Alberta laboratory in conjunction with the work of Lovsin (58). The data are for 57 subjects who worked on the bicycle ergometer at loads of 600, 900, and 1200 kpm., for periods of up to six minutes, interspersed by rests of five minutes. Forty subjects were able to complete the 1200 kpm. work, 17 were not, and on this basis were classified as 'fit' and 'unfit'. Mean values for heart-rate at 1 minute intervals are plotted for each group, against time. The curves show the tendency for duration of work, leading to higher heart-rates to increase the difference between groups. With regard to work-load, the relationship between the curves for 600 and 900 kpm. is almost identical. However, data collected for the first 24 subjects, (who were grouped according to the same criterion - 17 fit, and 7 unfit) showed that at the end of the 300 kpm. load the difference between groups was 6 b.p.m., as compared with 21 b.p.m. at 600 and 900 kpm. This suggests that a fairly large range of submaximal work, 600 - 900 kpm., if continued for sufficient duration, will provide a considerable range of fitness scores. Bearing in mind the evidence on reliability, it would seem that the higher the submaximal work, the better from the combined point of view of reliability and range of scores. The data for 1200 kpm. suggest that as work becomes maximal for some subjects, absolute levels of heart-rate are of little value. For some subjects heart-rate would level off, while for others, taking longer to reach maximal, heart-rate would still be rising, and the curves would therefore converge.

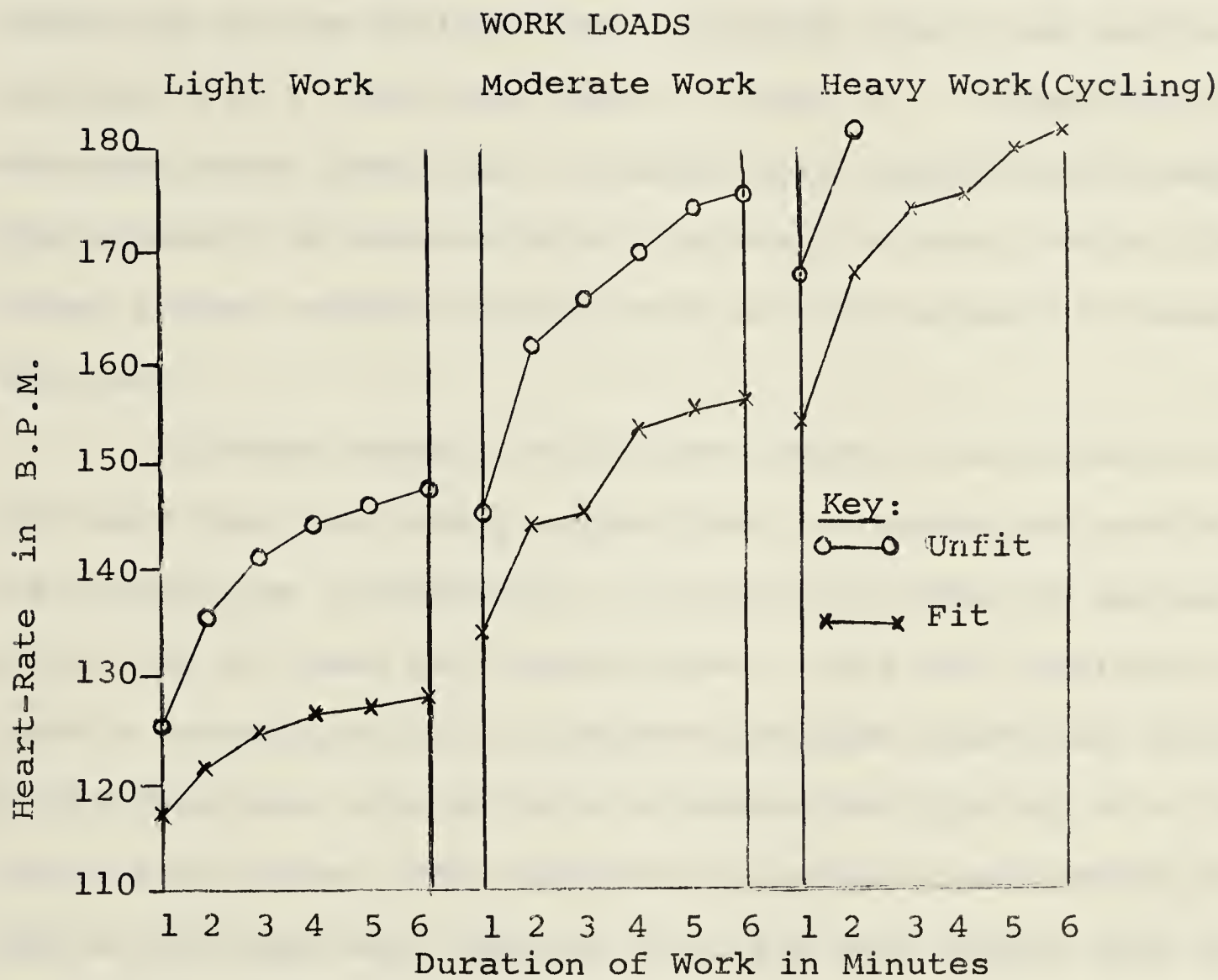

Figure 1. Mean Heart-Rates for 'fit' and 'unfit' Subjects in Light (600 kpm/min.), Moderate (900 kpm/min.), and Heavy Work (1200 kpm/min.) in Stationary Cycling.

When considering work which leads to maximal heart-rate in some or all of the subjects it would seem necessary to introduce a time function to make heart-rate comparisons meaningful. Boas (20) found that differences in maximal heart-rate were manifested not in the maximal level achieved (which was similar in all subjects) but in the time taken to reach it. Subjects who were exhausted after less than 3 minutes work reached their maximum rate approximately 90 seconds after the start of work, while those who worked longer reached maximum rate on the average 120 seconds after the start.

Although heart-rate has been shown to be closely correlated with work rate and energy expenditure in controlled conditions, its validity as a predictor of fitness in terms of maximal work output has not been well established. Borg and Dahlstrom (21) found a correlation of .51 between exercise heart-rate during work at 900 kpm./min. on a bicycle ergometer and placing in a long distance ski race. The correlations between heart-rates during work at 900 kpm./min. and the criterion were higher than those associated with work at 600 kpm./min.

Nagle and Bedecki (65) studied heart-rate time, that is the time to reach defined heart-rates, during maximal work which exhausted all subjects between ten and fifteen minutes. The correlation coefficients between heart-rate times and duration of running were: HRT* 150, 0.69, HRT 160, 0.76, HRT 170, 0.77, HRT 180, 0.85. Once agains this emphasizes the superior predictive value of heart-rate when counted during work leading to

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* Heart-rate time.

high rates.

Taylor (73) made a thorough investigation of the validity of heart-rate as a measure of fitness, his criterion of the latter being time-run on a treadmill to exhaustion. The correlations be-between submaximal heart-rate during walking and time-run, and heart-rate at the 3rd minute of running (the last time including all subjects) and time-run were 0.56 and 0.01 respectively. He regarded the first correlation as only moderate, and dismissed maximal heart-rate as not correlating with fitness. He found that acceleration of heart-rate correlated 0.77 and 0.78 with the criterion on two separate occasions. This function, combined with heart-rate at the mid-point of the run and with submaximal heart-rate gave correlations of 0.90 and 0.91 providing what he called a "highly valid battery".

Unfortunately, the counting of heart-rate in the course of field testing presents some difficulties. Without automatic recording devices it is difficult to count heart-rate during movement, especially when high rates are reached. The problem is less acute with bicycle ergometry.

Recovery Heart-Rate. Heart-rate counted in recovery has enjoyed the widest use in fitness testing. It usually figures in ratio type tests, such as the Harvard Step test and the Johnson, Brouha, and Darling test (49), in which heart-rate is related to duration of work.

Recovery heart-rate has been shown to reach a lower level as a result of training (3, 25, 28) and to reflect inter-individual differences in fitness in which respect Anderson (3) found

differences associated with age, occupational activity, and army training.

However, when monitored following maximal work there is little evidence that training affects recovery heart-rate. Knehr et al (53) showed that while training resulted in a 59.6% increase in work-done, maximal heart-rate did not change and recovery curves remained almost identical, and Cogswell et al (28) confirmed this phenomenon. Knehr et al (53) commented that his results did not run counter to the assumption that individual differences in performance can be related to decline of pulse-rate after moderate exercise. Kramer (61) stated that the recovery pulse curve from maximal or near maximal work loads is worthless as an index of physical and/or cardiovascular fitness in children.

It should perhaps be emphasized that recovery heart-rate provides two sources of fitness index which are quite distinct. First, it may reflect heart-rate achieved during work, and secondly the study of decelaration during recovery may be informative. With regard to the former, there is evidence that heart-rate counted shortly after exercise accurately reflects heart-rate at the end of exercise. Cotton (30) found that following work leading to heart-rates of 149 - 167 bpm., heart-rate for the first ten seconds after work was virtually the same as in the last ten seconds of exercise. He calculated that recovery heart-rate may be used to predict exercise heart-rate "with an error whose standard deviation is rather less than 3%." Elbel and Green (38) found that heart-rate counted immediately after light work accurately reflected work load, but that one minute after work heart-rate

bore little relation to work load. Le Blanc (56) found that heart-rate counted up to 15 seconds after exercise accurately reflected both intensity and duration of work, and heart-rate during work.

The evidence concerning the value of decelaration after exercise is much less clear. Robinson (69) showed that decelaration decreased with age, but it is not yet established at present that decelaration rate differentiates the fitness of persons of the same age group. Astrand's comment (13) previously referred to is relevant here. He suggested that recovery rate is of limited use since it varies from one person to another, even if fitness by other criteria is the same. Brouha (23), while indicating the value of maximal recovery heart-rate (dependent on the maximal in exercise) showed no change in the slope of the recovery curves after training, and hence no definite tendency with regard to decelaration. Taylor's curves (73) likewise showed no definite differences in decelaration for groups of varying fitness.

The behaviour of heart-rate in recovery is largely governed by the intensity and duration of the preceding exercise (1, 47, 64), and the same factors which influence the reliability and validity of heart-rate during work would seem to influence heart-rate in recovery. It seems likely that in general, the higher the recovery heart-rate following submaximal work, the more accurate is the prediction of fitness. Wahlund (79) examined the differences between normal subjects and heart-patients and well-conditioned subjects with respect to recovery from cycle-peddling. He found that differences between normal subjects and the other groups tended to become more statistically significant

as work load increased. Brouha and Heath (24) showed that on minute after exercise the difference in heart-rate between athletes and non-athletes was 26 b.p.m., while after four minutes when heart-rate had decreased considerably, it was only 18 b.p.m. Faine (39) found that the significance of differences between individual recovery values declined from early counts, that is 30 to 60 seconds after exercise, to later counts, that is 60 to 90 seconds after exercise. In conflict with these findings Patterson (66) found a correlation of .506 between heart-rate counted from 3½ to 4 minutes after stepping exercise and a maximal step test criterion, which was higher than the correlations associated with earlier counts of recovery heart-rate.

The validity of recovery heart-rate as an index of maximal work output shows little promise. Rasch and Pierson (68) found no correlation between heart-rate after submaximal work and finishing positions in a cross-country race. Heart-rate was counted from 1 to 1½ minutes after the submaximal exercise. Taylor (73) obtained low correlations between recovery heart-rate and time-run, the highest being .21 for heart-rate counted two minutes after light exercise (walking). The correlation of .506 obtained by Patterson (66) between recovery heart-rate and maximal stepping performance suggests perhaps that the validity of recovery heart-rate as a fitness index should be further investigated.

Summary. It appears from the material reviewed that only heart-rate counted during exercise enjoys convincing favour as a means of assessing fitness. Resting heart-rate, while indicating

differences between groups of athletes and non-athletes, seems too unstable owing to its susceptibility to a variety of environmental influences to have a useful predictive value. Maximal heart-rate also appears to be of little use. Recovery heart-rate figures in many tests, but its relation to fitness is less clear than exercise heart-rate, and some workers regard it with the same disfavour as resting heart-rate. The close similarity indicated by some authors between heart-rate at the end of exercise and in the first half-minute of recovery suggests that recovery heart-rate may predict fitness with a validity comparable to exercise heart-rate.

CHAPTER III

METHODS AND PROCEDURE

Subjects. There were 63 male subjects who were students and staff of the University of Alberta and soldiers from Griesbach Barracks, Edmonton, Alberta. These same subjects provided data for the work of Glassford (42) and Baycroft (16), and were given four or in some cases five tests in all. Only two of these, the Johnson, Brouha, and Darling Test (49), and the Astrand Test of Maximal Oxygen Intake (12) provided data for the present study. The remainder were the Mitchell, Sproule, and Chapman Maximal Oxygen Intake Test (61), the Taylor, Buskirk and Henschel Maximal Oxygen Consumption Test (74), and the Astrand-Ryhming Nomogram for the Prediction of Maximal Oxygen Intake from Submaximal Work (14). The Johnson, Brouha, and Darling Test was performed on the first testing occasion, the remaining tests following in order according to one of the 24 possible permutations for four tests with each subject selecting one permutation at random. The testing period for each subject varied from two to four weeks with a minimum of two and a maximum of seven days between tests.

Standardization of Procedure. Subjects. In order to standardize as far as possible the effects of conditions outside the laboratory the subjects were asked:

(a) To refrain from eating and smoking during the one and a half hours before a test.

(b) To take only a light meal before a test.

(c) To refrain from heavy exercise during the one and a half hours before a test.

(d) To make themselves available for testing at the same time each test day.

Testers. There were three testers, all of whom were familiar with test procedures and techniques. They each administered the same aspects of the tests throughout the experiments.

Laboratory Conditions. Testing was conducted in the Faculty of Physical Education Laboratory at the University of Alberta. It was not possible to control ambient temperature and humidity. However, temperature was 72 ± 4° F throughout, indicating a fair degree of stability.

Subject Orientation. A number of the subjects were already familiar with the forms of work and test procedures used. For the remainder, there was a short orientation period on the first visit to the laboratory during which they ran on the treadmill, pedalled the bicycle ergometer, and used the respiratory apparatus.

Heart-Rate Recordings. Heart-rate was recorded on a Sanborn 100 Viso-Electrocardiogram, the leads of which were attached to two chest electrodes situated just below the nipples in the fifth inter-costal space, and a reference electrode on the forehead. The electrodes were treated with Redux paste to minimize skin resistance. Heart-rate was calculated from the

length in millimetres occupied by a three beat complex on the E.C.G. recording paper.

Respiratory Apparatus. Otis-McKerrow two-way respiration valves with low resistance diaphragms were used. Gas was collected via a three foot, 1.5 inch diameter flexible plastic hose, in a 150 or 200 litre Douglas bag. A three-way Thomas valve controlled gas flow into the Douglas bags. Mouthpiece, respiration valve, and connecting tube were supported by a headgear which was adjustable to head-size.

Expired air was analysed for percentage of oxygen by a Beckman #E-2 oxygen analyser, and for percentage of carbon dioxide by a #KK Godart Capnograph infra-red carbon dioxide analyser. Both instruments were calibrated before each testing occasion, and at intervals during tests.

The volume of expired air was measured by an #802 American Meter Company Gasometer through which air was pumped by means of a Collins #p. 553, 1/15 horsepower centrifugal pump at a rate of 70 litres per minute. Approximately half-way through the experimental period this instrument was found to have a 6% error which was sufficient to invalidate all preceding measures. Being a constant error it was possible to introduce a correction factor, and to re-calculate measures of oxygen intake.* A Collins Chain-Compensated Gasometer with a capacity of 120 litres and a factor of 133.2 cc/min. was used in checking the American Metre Co. Gasometer.

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* See Appendix V

Determination of Oxygen Consumption. The principle underlying the calculation of oxygen consumption was the change in nitrogen content for correction of expired to inspired volumes, described by Peters and Van Slyke (67). The Symbols and method used in the calculation are shown below:

1. Symbols.

   (a) Fe = % of a particular gas in expired air.

   (b) Fi = % of a particular gas in inspired air.

   (c) Ve = Volume expired.

   (d) Vi = Volume inspired.

   (e) ATPS = Atmospheric temperature, pressure, saturated.

   (f) STPD = Standard temperature, pressure, dry.

2. The corrected volume of air expired is:

   Ve air STPD = Ve ATPS X the factor for reducing a volume of moist gas to a volume of dry gas at 0° C and 760 mm of mercury.

3. The corrected per cent of oxygen in the expired air is:

   $$Fe\ O_2 = \text{Analyser reading} \times \frac{2.5}{1000}$$

4. The volume of inspired air is:

   $$Vi\ \text{air STPD} = Ve\ \text{air STPD} \times \frac{Fe\ N_2}{Fi\ N_2} \quad (Fi\ N_2 = 79.03)$$

5. The total volume of oxygen inspired (not all consumed) is:

   $$Vi\ O_2 = Vi\ \text{air} \times \frac{Fi\ O_2}{100} \quad (Fi\ O_2 = 20.94)$$

6. The volume of oxygen expired (not consumed) is:

   $$Ve\ O_2 = \frac{Fe\ O_2}{100} \times Ve\ \text{air}$$

7. The amount of oxygen consumed is:

$$VO_2 = Vi\ O_2 - Ve\ O_2$$

Resting Heart-Rate. This was measured prior to the Johnson, Brouha, and Darling test. The subject was recumbent in an isolated room for between 20 and 30 minutes. After 15 minutes rest heart-rate was counted by palpation at one minute intervals until it was steady (± 2 beats) for two consecutive counts. The lower of these counts represented resting heart-rate, unless a preceding count was lower in which case that value was recorded. If heart-rate fell continuously, never reaching a steady-state, the count at 30 minutes was recorded.

1. Tests.

The Johnson, Brouha, and Darling Test (49).

This test provided:

(a) The criterion measure of 'direct' fitness, in the form of time-run in seconds by those subjects running less than the maximum 5 minutes.

(b) One criterion measure of 'ratio' fitness, in the form of the fitness index, for all subjects, calculated from time-run and recovery heart-rate.

(c) Exercise heart-rate during submaximal heavy work (running).

(d) Maximal heart-rate.

(e) Recovery heart-rate following heavy work (running) leading to maximal heart-rate.

(f) Rate of heart-rate recovery following work leading to maximal heart-rate.

The test was administered on the first test occasion, following the measurement of resting heart-rate. The procedure was as follows:

1. The subject 'warmed-up' by walking on an 8.6% grade, at 3.5 m.p.h., for 5 minutes.
2. He rested, seated, for 5 minutes, during which time electrodes for E.C.G. readings were attached.
3. He then ran at a speed of 7 m.p.h. on an 8.6% grade for as long as possible up to a maximum of 5 minutes. Duration of run was recorded to the nearest second on a stopwatch. One tester operated the treadmill and the E.C.G., the second placed a chair on the treadmill as soon as the run was finished and seated the subject, and the third timed the run.

Exercise Heart-Rates. Heart-rate was recorded during exercise for the 3 second periods preceding every quarter minute for the first minute, (i.e. the 15th second, 30th second, etc.) and every 30th second until the run was completed. The heart-rates up to 2 minutes, the last time at which all subjects were running, constituted heart-rate response to submaximal heavy work (running). The highest rate obtained, almost invariably the final count, constituted maximal heart-rate.

Recovery Heart-Rates. Heart-rate was recorded for the three second periods following the 5th second of recovery, every 15th second up to 1 minute, 1.5 minutes, 2 minutes, 3 minutes, and 4 minutes. These recording constituted heart-rate recovery from

heavy work (running) leading to maximal heart-rate. In addition, for purposes of calculating the fitness index, heart-rate from 1 to 1.5 minutes, 2 to 2.5 minutes, and 4 to 4.5 minutes after exercise was recorded.

Rate of Heart-Rate Recovery. This was calculated by subtracting recovery heart-rate 1 minute after work, from the final exercise heart-rate.

Time Run. This was measured to the nearest second.

The Fitness Index (49). This was calculated from the formula:

$$\frac{\text{Time-run in seconds} \times 100}{2\text{x (the sum of 3 half-minute heart-rate counts)}}$$

2. The Astrand Bicycle Ergometer Test of Maximal Oxygen Intake (Modified). This test provided:

(a) The criterion measure of 'indirect fitness', that is, maximal oxygen intake.

(b) A second 'ratio' measure of fitness in terms of work done in reaching maximal oxygen intake.

(c) Exercise heart-rate during light, moderate, and heavy work (cycling).

(d) Recovery heart-rate for these loads.

(e) Rate of heart-rate recovery for these loads.

The test was administered in a manner closely simulating Astrand's descriptions (7, 9, 12). It was modified insofar as maximal oxygen intake was obtained in one session of testing, rather than in two or more sessions.

A Monark Bicycle Ergometer was used (78), with saddle height adjusted so that with the peddle at its lowest point the subject's knee-cap was directly above the instep of the foot. Two chest electrodes and one forehead electrode were attached to the subject. The subject was required to peddle at 50 r.p.m., paced by an electric metronome. The brake belt which controlled the resistance to pedalling was slack at the start of each work period, and was adjusted to the desired load as soon as pedalling started. The adjustment of the load was checked once every minute.

One tester timed the procedure, and recorded heart-rates, while the second controlled the brake belt, took gas samples, and analysed them. The test proceeded as follows:

(a) The subject worked for periods of six minutes each against progressively increased loads, with rests of five minutes between during which the subject remained seated on the cycle.

(b) Work loads were 600, 900, 1200, 1500, 1800, 1950, and 2100 kpm/min.

(c) The work loads of 600, 900, and 1200 kpm. constituted light, moderate, and heavy work (cycling) respectively.

(d) Gas samples were collected from the 5th to the 6th minute of each work load which was completed. When subjects were unable to complete a load they were asked to indicate the approach of exhaustion, and a 15-second, 30-second, or 45-second gas sample was taken.

(e) The criterion of maximal oxygen was reached when the

subject's oxygen intake failed to increase by 0.081 millilitres or more over the oxygen intake for the previous work load (9).

Exercise Heart-Rates. Recordings of exercise heart-rate were taken during the three second period preceding the end of each minute of exercise. The loads of 600 and 900 kpm/min. provided records of exercise heart-rate during light and moderate work respectively, and the load of 1200 kpm/min. provided the record of heart-rate during heavy work (cycling).

Recovery Heart-Rates. These were recorded at the same time intervals as those following the Johnson, Brouha, and Darling test. In this manner recovery heart-rates for light, moderate, and heavy work (cycling) were obtained.

Rate of Heart-Rate Recovery. For each work load rate of heart-rate recovery was obtained by subtracting recovery heart-rate 1 minute after exercise from final exercise heart-rate.

Work Done in Reaching Maximal Oxygen Intake. This was calculated as follows:

(a) by multiplying rate of work by duration of work for each load, and

(b) by adding the work done at each load up to and including that in which maximal oxygen intake was obtained.

Example: One subject completed the loads of 600, 900, and 1200 kpm/min., pedalled 3-1/4 minutes at 1500, and 1-1/2 minutes at 1800 kpm. His oxygen intake rose in half litre steps up to the 1500 load, from which a 15-second gas sample, taken immediately before he reached exhaustion at 3-1/4 minutes, gave an oxygen intake rate of 4.562 litres per minute. Following rest he worked for 1-1/2 minutes at 1800 kpm/min., but only achieved an oxygen intake of 4.489 litres per minute. Work done was therefore calculated to the third minute and one quarter of the 1500 kpm/min. load, as follows:

(a) Work rate X duration for each load -

600 kpm/min. x 6 = 3600 kpm.

900 kpm/min. x 6 = 5400 kpm.

1200 kpm/min. x 6 = 7200 kpm.

1500 kpm/min. x 3-1/2 = 5250 kpm.

(b) The sum of these = 21450 kpm. = work done in reaching maximal oxygen intake. Since all subjects completed the 600 and 900 kpm/min. loads these were not included in the calculation.

Statistical Treatment. Correlation coefficients were obtained between all variables by an I.B.M. - 1620 Electronic Computer programme of simple correlation (Number 1620-013) which also provided the mean, variance, and standard deviation for each variable. The significance of the differences between two correlation coefficients for correlated samples was calculated by a t-test (40:154). Two forms of t-test were used to calculate

the significance of the difference between means for independent samples - one for the difference between means of equal variance (40:136), the other for the difference between means of unequal variance (40:143). An F test (40:140) was used to ascertain homogeneity of variance before the application of these t-tests. To evaluate some possible spurious elements influencing certain correlation coefficients, partial correlations were calculated (40:290).

CHAPTER IV

RESULTS AND DISCUSSION

Subject Groupings. Of the sixty-three subjects tested complete data were obtained for only thirty-six. Certain data were lost owing to absence of subjects on test days, and the remainder, as a result of technical difficulties which occurred during testing. Four subjects had complete data except for one or two isolated heart-rate counts. These were estimated*, thus completing the data for forty subjects who constituted the main sample, designated Sample 1. Reference is made to three other samples within the main sample as follows: Sample 2 - This groups consisted of 22 subjects all of whom ran less than five minutes in the Johnson, Brouha, and Darling Test, and who were the source of correlations involving time-run. These subjects were described as 'less fit'. Sample 3 - There were 19 subjects in this group, comprising those who completed 5 minutes running in the Johnson, Brouha, and Darling Test. These subjects are described as 'fit'. Sample 4 - All the subjects in the main sample completed 6 minutes of cycling at loads of 600 and 900 kpm/min. The 29 subjects in this sample in addition, completed six minutes at 1200 kpm/minute (heavy work, cycling).

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* See Appendix C.

Sixteen of these figured in Sample 3, having completed five minutes running in the Johnson, Brouha, and Darling Test.

Sample 1 is the major concern of this report. Reference is made to the other samples to illustrate differences between 'fit' and 'less fit' subjects and to emphasise correlation trends observed in the main sample. Sample 4 is useful insofar as the extra submaximal cycling load extends the range of heart-rates being correlated with fitness criteria.

Interpretation of the Correlation Coefficient. Correlation coefficients are interpreted in terms of variance (60:129) in which the square of the correlation coefficient, r^2, gives the proportion of the total variance of Y which is predictable from X, or vice versa. The proportion of the variance of Y due to variables other than X is given by $1 - r^2$. By multiplying r^2 and $1 - r^2$ by 100 the explained and unexplained variance may be expressed in percentage terms. When r's are discussed, they are reported, for example, in the following form: $r_{12} = -.50$ (25%) $P = .01$, the figures representing the r, r^2% (percentage of variance common to both variables), and the statistical significance of the r.

McNemar (60:168) has pointed out that the correlation coefficient presents no easy way to scientific discovery. It is affected by many factors including homogeneity of variance, reliability, and sampling errors. In interpreting the findings of this study there are two serious limitations:

(a) correlations concerning time-run, are for 22 'less fit' subjects, whereas correlations concerning other fitness criteria are for 40 subjects includings 'fit' and 'less fit'. The selective nature of the sample concerned in the former case may act to increase homogeneity of variance in one or both of the variables concerned resulting in decreased correlations. Thus correlations for time-run are not comparable with those based on Sample 1.

(b) reliability coefficients were not computed for any variables. This limitation is serious since one of the chief factors distinguishing the predictive value of resting, exercise, and recovery heart-rates is reliability.

For purposes of this study correlations are classified, with respect to their predictive quality, as follows:

(a) low = less than .45 (20%)

(b) moderate = .45 to .71 (50%)

(c) high = greater than .71

This scale is based on the notion that the criteria of fitness used here are expressions of highly complex mechanisms. This being so it is not reasonable to expect the variance of an isolated factor such as heart-rate to predict with accuracy the variance of parameters which quite obviously reflect numerous factors.

Fitness Characteristics of Samples 1 to 4. The mean values and standard deviations for all variables and for all four

samples are given in Appendix D.

From Table I, which compares some mean values for Samples 2 and 3, it is clear that the 'less fit' and 'fit' groups differed considerably. Apart from the difference in time-run, on the basis of which the groups were classified, the 'fit' group had a higher maximal oxygen intake, performed more work before reaching maximal oxygen intake, and had a lower resting heart-rate. These differences were all significant at the 1% level as were the differences in heart-rate during exercise at 1 minutes and 6 minutes of light and moderate work, at 30 seconds and 2 minutes of heavy work (running), and at 5 seconds of recovery for light and moderate work loads. Differences were not significant for maximal heart-rate, body-weight, rate of heart-rate recovery from the three work loads, and recovery heart-rate 5 seconds after heavy work (running).

These group differences indicate a certain amount of agreement between the different fitness criteria in distinguishing the two groups. The significant differences in resting heart-rate and selected exercise and recovery heart-rates are a preliminary, though superficial, indication of the validity of certain heart-rate counts in predicting fitness. The correlation data subjects these indications to a closer scrutiny.

The finding that maximal heart-rate was the same for 'fit' and 'less fit' subjects supports the findings of Boas (20), Knehr et al (53) and Cogswell et al (28). The inadequacy of recovery rate in distinguishing 'fit' from 'less fit' is in agreement with the findings of Kramer (55), Knehr et al (53) and Cogswell et al (28) with respect to recovery from maximal or near maximal

TABLE I

Mean Values, Variances, F Ratios, Differences Between Means, and t Ratios for Sample 3 ('fit', N = 18) and Sample 2 ('less fit', N = 22) for Various Parameters

	Wt. in kgms.	Max. VO_2 litres/ min.	Max. VO_2 mls/kg/ min.	Work Done	Resting H-R	JBD Index	Max. H-R	H-R at 1 min. 600 kpm.	H-R at 6 min. 600 kpm.
Sample 3									
Mean	75.02	3.67	49.10	15927	61	80.2	191	110	116
Variance	57.251	.145	17.462	35305970	37.83	84.829	56.732	82.811	120.853
Sample 2									
Mean	74.71	3.16	42.63	9413	71	47.045	194	122	133
Variance	88.953	.135	25.006	23887238	93.570	178.956	39.905	142.433	274.262
F Ratio	1.554	1.074	1.437	1.478	2.473	2.110	1.422	1.720	2.269
Difference Between Means	.31	.51	6.47	6514	10	33.2	3	12	17
t Ratio	113	4.47***	4.37***	3.81***	3.80***	8.930***	1.370	3.51**	3.73***

H-R - Heart-Rate.
* - Significant at 5% level.
** - Significant at 1% level.
*** - Significant at .1% level.
Max. VO2 - Maximal Oxygen Intake.

TABLE I (Continued)

	H-R at 1 min. 900 kpm.	H-R at 6 min. 900 kpm.	H-R at 30 secs. Heavy Running	H-R at 2 in. Heavy Running	H-R at 5 secs. Recov., 600 kpm.	H-R at 5 secs. Recov., 900 kpm.	H-R at 5 secs. Recov. Heavy Running
Sample 3							
Mean	129	143	160	180	110	138	188
Variance	83.794	137.794	118.147	35.389	91.125	159.742	59.296
Sample 2							
Mean	141	158	171	190	125	152	193
Variance	180.704	247.212	111.420	64.929	277.957	321.396	62.944
F Ratio	2.157	1.794	1.060	1.835	3.050*	2.012	1.062
Difference Between Means	12	15	11	10	15	14	5
t Ratio	3.22**	3.35**	3.24**	4.37***	3.57***	2.79**	2.01

H-R - Heart-Rate.
* - Significant at 5% level.
** - Significant at 1% level.
*** - Significant at .1% level.

TABLE I (Continued)

	Recov. Rate 600 kpm.	Recov. Rate 900 kpm.	Recov. Rate Heavy Running
Sample 3			
Mean	34	44	41
Variance	118.147	85.036	117.232
Sample 2			
Mean	36	41	37
Variance	102.349	71.515	134.944
F Ratio	1.154	1.189	1.151
Difference Between Means	2	3	4
t Ratio	0.60	1.07	1.117

work. It also appears true of submaximal work leading to moderately high heart-rates. Knehr et al (53) have already been referred to as suggesting that individual differences in performance can be related to decline of heart-rate after sub-maximal exercise. This suggestion gains no support from the present data.

The Effects of Different Work Loads on Exercise Heart-Rate Heart-rates during light, moderate and heavy work (running) for Samples 1 and 4, and for heavy work (cycling) for Sample 4 are illustrated in Figure 2, which seems to show adequate justification for the terms light, moderate, and heavy work.

For Sample 1, mean heart-rate during light work ranged from 116 b.p.m. after 1 minute to 125 at the sixth; for moderate work the range was 135 and 152; for heavy work (running) the mean heart-rate rose from 157 after 15 seconds to 185 after 2 minutes, which was the last time all subjects were running.

For Sample 4, heavy work (cycling) introduced a range of heart-rate response between moderate work and heavy work (running). The curves for both samples demonstrate an approximate linear relationship between work load and heart-rate. In this respect the curve for Sample 4, with its additional submaximal load (1200 kpm/min.) is particularly clear.

Standard Deviations of Heart-Rates According to Johnson et al (49) the lower the work-rate the smaller are the differences between fit and unfit subjects. Some evidence in support of this, with respect to heart-rate has already been cited (24, 58), and the standard deviations of heart-rates obtained from the different

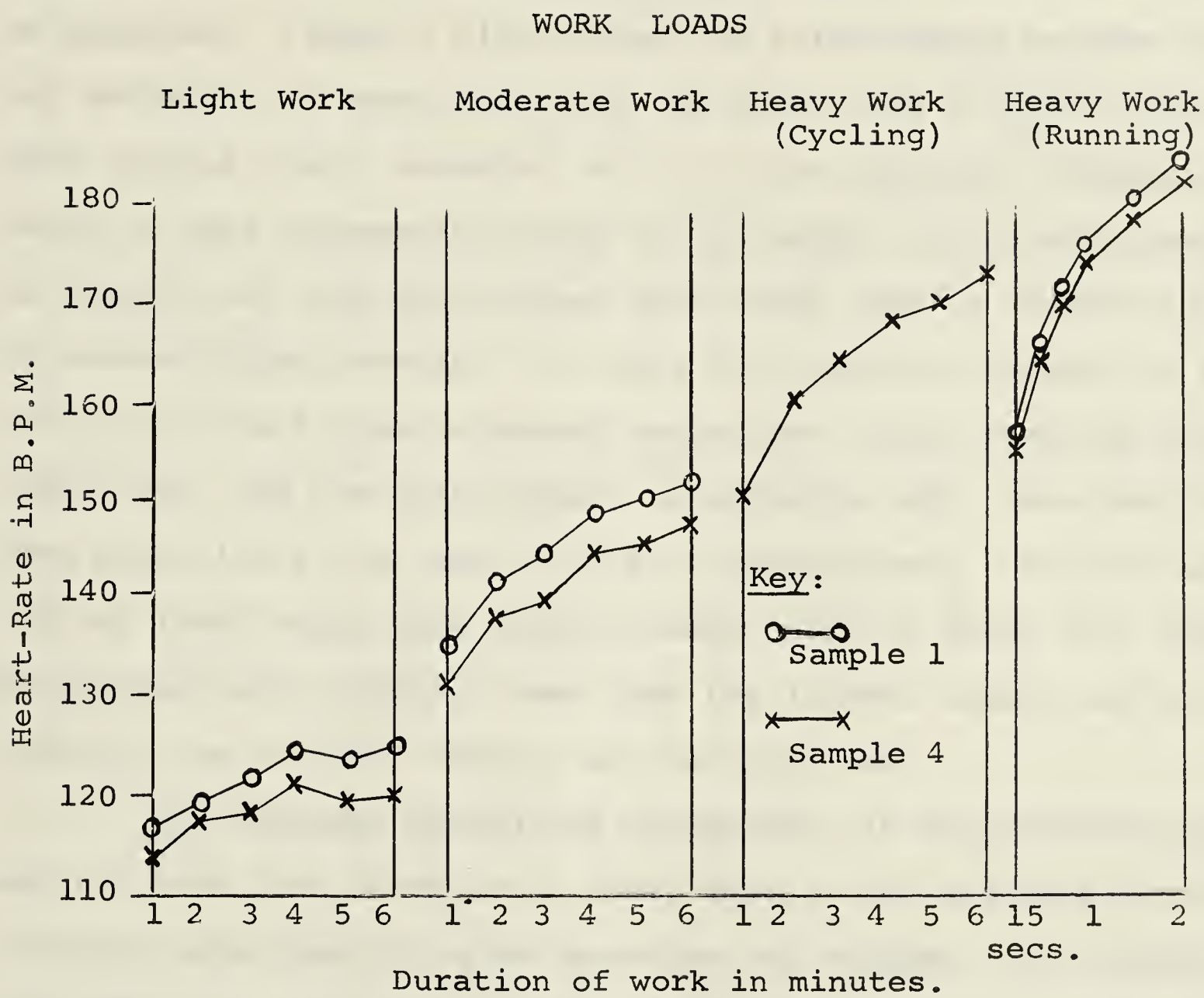


Figure 2. Mean Heart-Rates for Sample 1 (N = 40) and Sample 4 (N = 29) in Light, Moderate, and Heavy Work (Cycling) and Heavy Work (Running).

work loads used in this study provide further relevant information. If increasing work loads result in increased spread of scores (difference between subjects) then increased standard deviations are to be expected. Figure 3 illustrates the relationship between standard deviation of heart-rates and the conditions in which heart-rates were counted (rest, exercise, etc.). From the data for Sample 4, which is more informative owing to the extra cycling work-load, it is clearly not true that higher work-loads lead to greater spread of scores during exercise. In fact the opposite tendency is indicated since the highest standard deviations during exercise were in light work, and the next highest in moderate work, when heart-rates were about 120 b.p.m. and 150 b.p.m. respectively. For the extra cycling load, which gave rise to heart-rates of about 170, standard deviations were slightly lower than the lighter loads, and were still lower in the Johnson, Brouha, and Darling test.

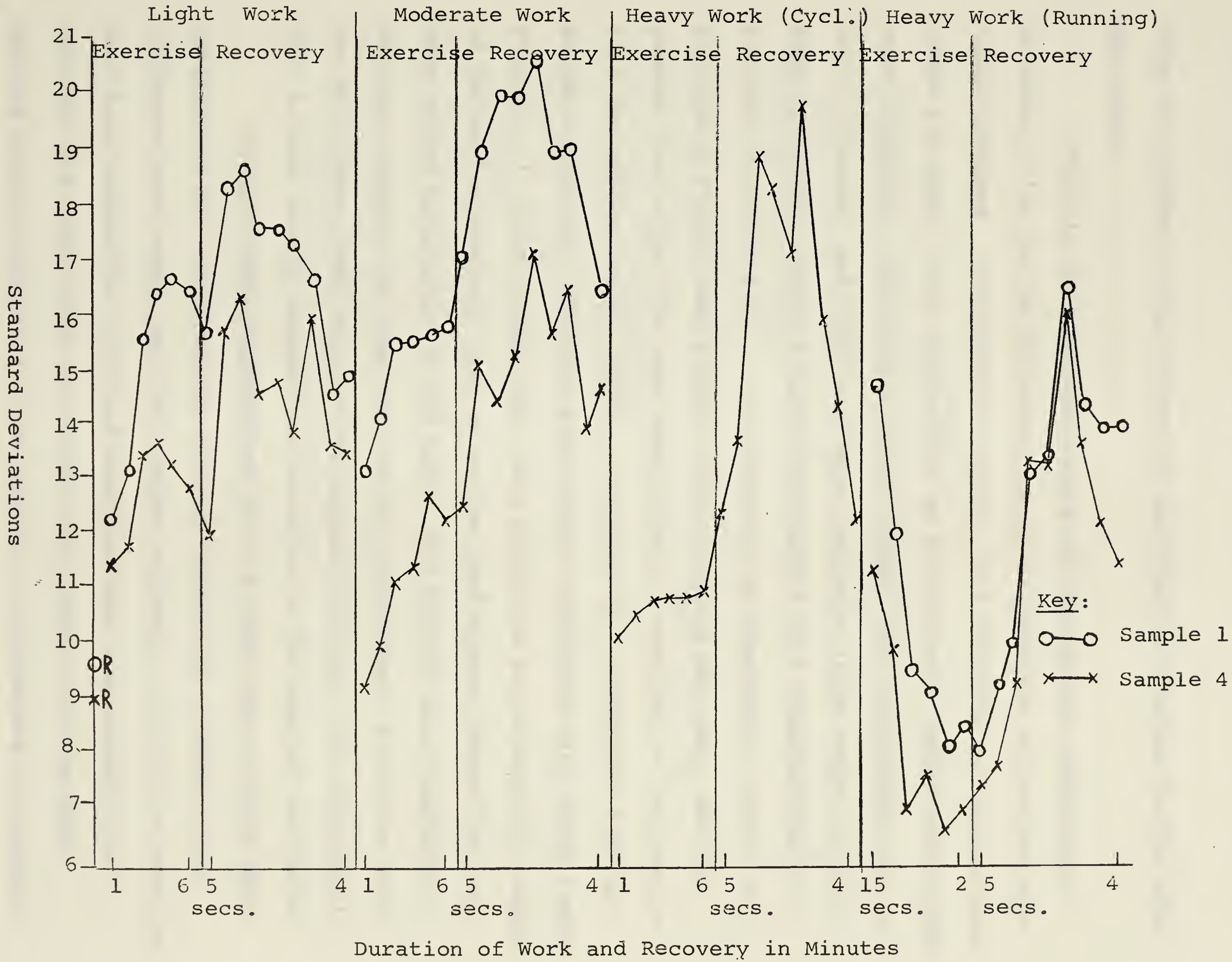
The greatest spread was undoubtedly in the recovery periods and for each load there was a sharp rise in the standard deviation of heart-rates shortly after exercise had stopped. The immediate post-exercise count had a standard deviation similar to that of the last exercise count.

These phenomena are discussed later, when the predictive values of heart-rates at rest, during exercise, and after exercise are compared.

Interrelationships Between Fitness Criterion Measures

Some basic differences in the nature of the fitness criteria have already been noted. Although all the measures concern the same

Figure 3. Standard Deviations of Heart-Rates at Rest, During Exercise and Recovery For Sample 1 (N = 40 and Sample 4 (N = 29).



type of fitness, a fair degree of specificity from one to the other may exist.

Possibly the greatest source of specificity, assuming it to exist, lies in the different use of body-weight in the two work tasks involved. In treadmill running, all subjects ran at the same grade and speed, with body-weight as the decisive factor determining work intensity. In cycling against fixed loads body-weight had no such influence, and light and heavy subjects alike worked at the same intensity. While a large body-weight is a disadvantage in running, in cycling it is, if anything, an advantage. First, it provides a stable base against which the legs may work, and the greater the weight the less stabilizing is required of the arms to hold the subject on the saddle, allowing him to exploit his leg drive to the full. This is particularly important with heavy loads. Secondly, it seems likely that each subject's leg strength is adapted to his body-weight, that is to the load against which the legs have worked habitually in the past. The heavier man, therefore, peddling against the same load as the lighter man, should be working at a lower level relative to maximal ability, and consequently with a lower energy expenditure relative to the maximal available.

Clearly these differences must be taken into account when considering the relationships between heart-rate obtained from different work tasks, and the fitness criteria. It will be recalled that heart-rates for light and moderate work were gained from cycling, and heart-rates for heavy work (except for the extra cycling load for Sample 4) from running. Differences in correlations concerning heart-rates between the heavy load and the lighter

loads may be a function of specificity to some extent, as well as a function of work intensity.

The correlations between fitness criteria are shown in Table II, and body-weight is included.

TABLE II

Correlation Coefficients Between Different Measures of Fitness and Body-weight, for Sample[1], (N = 40)

Tests	1	2	3	4	5	6
1. Maximal Oxygen Intake in litres/min.			.52**	.75**	.66**	.48**	.48†
2. Maximal Oxygen Intake in mls/kg/min.				.42**	.64**	-.36*	.38
3. Work Done to Reach Maximal Oxygen Intake					.63**	.40*	.79††
4. Johnson, Brouha and Darling Fitness Index						.05	.96††
5. Body-Weight							.03
6. Time-Run (Sample 2, N = 22)							

* - Significant at the 5% level, N = 40.
** - Significant at the 1% level, N = 40.
† - Significant at the 5% level, N = 22.
†† - Significant at the 1% level, N = 22.

Correlations Between Body-Weight and Fitness Criterion Measures. Body-weight correlated significantly with maximal oxygen intake expressed in litres/min. and mls/kg/min., and work-done to reach maximal oxygen intake. The correlations were low, or moderate as in the case of body-weight vs. maximal oxygen intake in litres/min., but they were sufficient to show that body-weight influenced these variables. There is evidence to support

this in the case of maximal oxygen intake in litres/min. (26, 27, 80). The negative correlation of -.36 (13%), P = .05, between maximal oxygen intake expressed as a proportion of body-weight, and body-weight, suggests that the lighter subjects were equipped with a more favourable ratio of available energy to the mass to be driven. This may indicate that a greater proportion of body-weight was active tissue in lighter subjects.

It is observed that body-weight did not correlate with time-run and the Johnson, Brouha, and Darling Fitness Index. This finding appears to verify the distinction made above between the different functions of body-weight in stationary cycling and running.

Maximal Oxygen Intake, Time-Run, and the Johnson, Brouha, and Darling Fitness Index (JBD Index). The correlations between maximal oxygen intake in litres/min. and mls/kg/min., and time-run were respectively .48 (23%) P = .05, and, .38 (14%) NS, indicating that those subjects with a higher maximal oxygen intake, irrespective of body-weight, were able to run longer. One might have expected oxygen intake as a proportion of body-weight to be more closely related to time-run than its absolute counterpart since it is usually suggested (13), that maximal oxygen intake relative to body-weight is the more accurate predictor of fitness. That this suggestion is not borne out here may reflect the specific form of work from which maximal oxygen intake was obtained. It was mentioned earlier that the subjects in this experiment also underwent the Mitchell, Sproule, and Chapman Test of Maximal Oxygen Consumption (61) in connection with another study (42). This treadmill test gave a significantly higher mean value than

the cycle test, 3.60 litres/min. as against 3.39 litres/min. and the correlations between it and time-run were:

mls/kg/min. - .50 (25%) P = .05

litres/min. - .33 (10%) NS

The situation was reversed, with the relative expression of oxygen intake more closely predicting time-run than the absolute expression. This difference between correlations involving different methods of maximal oxygen intake measurement, emphasises the specificity of variance from one test to the other, and the need for caution in generalizing from results.

The relationship between maximal oxygen intake and time-run represents sub-problem (a), and constitutes the relationship between an indirect and a direct measure of fitness. The correlation of .48 quoted above comes at the lower end of the 'moderate' classification adopted for this study. However, it should be remembered that this relationship included the 22 subjects of the 'less fit' category, thus decreasing the heterogeneity of variance and possibly the correlation coefficient.

The correlation between maximal oxygen intake in litres/min. and the Index was .66 (43%) P = .01, there being no significant difference between this and the coefficient of .64 (41%) P = .01 for oxygen intake expressed in mls/kg/min. and the Index. These correlations indicate a fair correspondence between an indirect fitness criterion and a ratio criterion.

The fact that the correlations for time-run and the Johnson, Brouha, and Darling Fitness Index vs. maximal oxygen intake left a large proportion of unexplained variance suggests

that variables in addition to aerobic capacity are involved in the treadmill performance. Motivation is certainly an important factor and anaerobic work may be involved to a great extent. The rapid rise of heart-rate shown in Figure 2 is testimony to a high rate of energy expenditure, and it seems likely that anaerobic processes are required to enable such rapid metabolism. Motivational factors are no doubt closely associated with the intense discomfort, both local and general, which most subjects experience in this test.

It is possible that a much less intense test of direct fitness might reduce the influence of anaerobic processes, and result in a higher correlation between aerobic capacity and fitness.

Time-Run and the Johnson, Brouha, and Darling Fitness Index

It is interesting to note that the correlation between time-run and the Index (Sample 2, N = 22) was .96, and that none of the correlations between recovery heart-rate following the test was significantly correlated with time-run or the Index. These findings indicate that for subjects running less than 5 minutes, time-run dominates the Fitness Index, and that heart-rate recovery served no useful function in differentiating between them. This of course, was not the case with Sample 3 (N = 18) in which all subjects ran 5 minutes and were differentiated solely in terms of recovery heart-rate. For this sample correlations between the index and recovery heart-rates were between -.89 and -.96 for the period 1 - 4 minutes after exercise.

Maximal Oxygen Intake and Work-Done to Achieve Maximal Oxygen Intake. The correlation between these two variables, representing sub-problem (b) was .75 (56%) P = .01 when maximal oxygen intake was expressed in litres/minute. This is classed as a high correlation. In showing a close correspondence between the variables it provides evidence for the validity of maximal oxygen intake as a factor decisive in work ability. The correlation between maximal oxygen intake in mls/kg/min. and work-done was .42 (18%) P = .01.

Correlations Between Work-Done to Reach Maximal Oxygen Intake, Time-Run, and the Johnson, Brouha, and Darling Fitness Index. The relationship between work-done and time-run constitutes sub-problem (c). The correlation was .79 (62%) P = .01 which is a high correlation, particularly when we remember that it involved the 'less fit' group only, with consequent decrease of heterogeneity. It seems that the ability to work aerobically is an important determinant of work ability in the Johnson, Brouha, and Darling treadmill run, in spite of the considerable differences in the types of work involved in the two tests. It is particularly interesting that such a high relationship should occur where one variable, work-done to reach maximal oxygen intake, is theoretically independent of motivation, and the other, time-run, may depend on it to a great extent.

The correlation between work-done and the Index was .82 (67%) P = .01 for Sample 2, and .63 (40%) P = .01 for Sample 1.

Summary. The correlations reported so far indicated the following:

(a) Maximal oxygen intake expressed in litres/min., (absolute) was more closely related to work-done to reach maximal oxygen intake, time-run, and the Johnson Brouha, and Darling Fitness Index, than when expressed in mls/kg/mins., (relative). This finding casts some doubt on the usefulness of the relative expression of maximal oxygen intake. However, it was shown that this phenomenon may reflect to some extent the form of work associated with the measurement of oxygen intake.

(b) A close relationship was found between maximal oxygen intake in litres/min. and work-done to achieve it, reflecting the validity of maximal oxygen intake as an index of fitness for prolonged heavy work.

(c) The Johnson, Brouha, and Darling Fitness Index and time-run were virtually the same thing for subjects running less than 5 minutes in the treadmill test and for such subjects the inclusion of heart-rate recovery in the index was superfluous. This was not the case for subjects who completed five minutes running, and were differentiated by heart-rate recovery alone.

(d) In spite of the very different characteristics of stationary cycling and time-run, those subjects who did well on one test tended to do well on the other in terms of work-output.

The Relationship Between Resting Heart-Rate and Fitness.

Table III shows the correlation coefficients between resting heart-rate and the various criteria of fitness and body-weight for Sample 1.

TABLE III

Correlation Coefficients Between Resting Heart-Rate Measures of Fitness, and Body-Weight for Sample 1, N = 40.

Tests				
Maximal Oxygen Intake, Litres/min.	Maximal Oxygen Intake mls/kg/min.	Work-Done to Reach Maximal Oxygen Intake	JBD Index	Body Weight
-.49(24%) P=.01	-.25(6%) NS	-.43(18%) P=.01	-.54(29%) P=.01	-.31 (10%) NS

Resting Heart-Rate and Maximal Oxygen Intake. A correlation of -.49(24%) P=.01 was obtained between resting heart-rate and maximal oxygen intake in litres/minute. The correlation between resting heart-rate and maximal oxygen intake in mls/kg/min. was not significant.

Resting Heart-Rate and Work-Done to Achieve Maximal Oxygen Intake. The correlation between these two variables was -.43 (18%) P = .01 which is almost in the moderate class.

Resting Heart-Rate and the Johnson, Brouha, and Darling Fitness Index. The correlation between these variables was -.54 (29%) P = .01, showing that heart-rate in the resting state reflects fitness for strenuous exertion as tested in the Johnson, Brouha, and Darling test to a moderate extent.

Resting Heart-Rate and Time-Run. A correlation of -.15 (NS) was obtained between resting heart-rate and time-run for Sample 2 (N = 22) showing no relationship between resting heart-rate and this measure of fitness. For the same group, the correlation between resting heart-rate and the JBD Index was -.18 (NS), much lower than the corresponding correlation for Sample 1 of -.54. This difference may reflect the difference in heterogeneity from one sample to the other, and it may be that the smaller heterogeneity of Sample 2 influenced the time-run correlation in a similar way. Alternatively, the difference may cast some doubt on the meaning of the correlation for Sample 1 (-.54) which may be relatively high because of the correlation between resting heart-rate and recovery heart-rate as it figures in the Index. Table IV show the correlations between resting heart-rate and recovery heart-rates at 1 minute, 1.5 minutes, 2 minutes, 3 minutes, and 4 minutes of recovery for Samples 1, 2, and 3, and correlations between resting heart-rate and the Fitness Index.

TABLE IV

Correlation Coefficients Between Resting Heart-Rate and Recovery Heart-Rate for Sample 1, 2, and 3, and Between Resting Heart-Rate and the Johnson, Brouha, and Darling Fitness Test

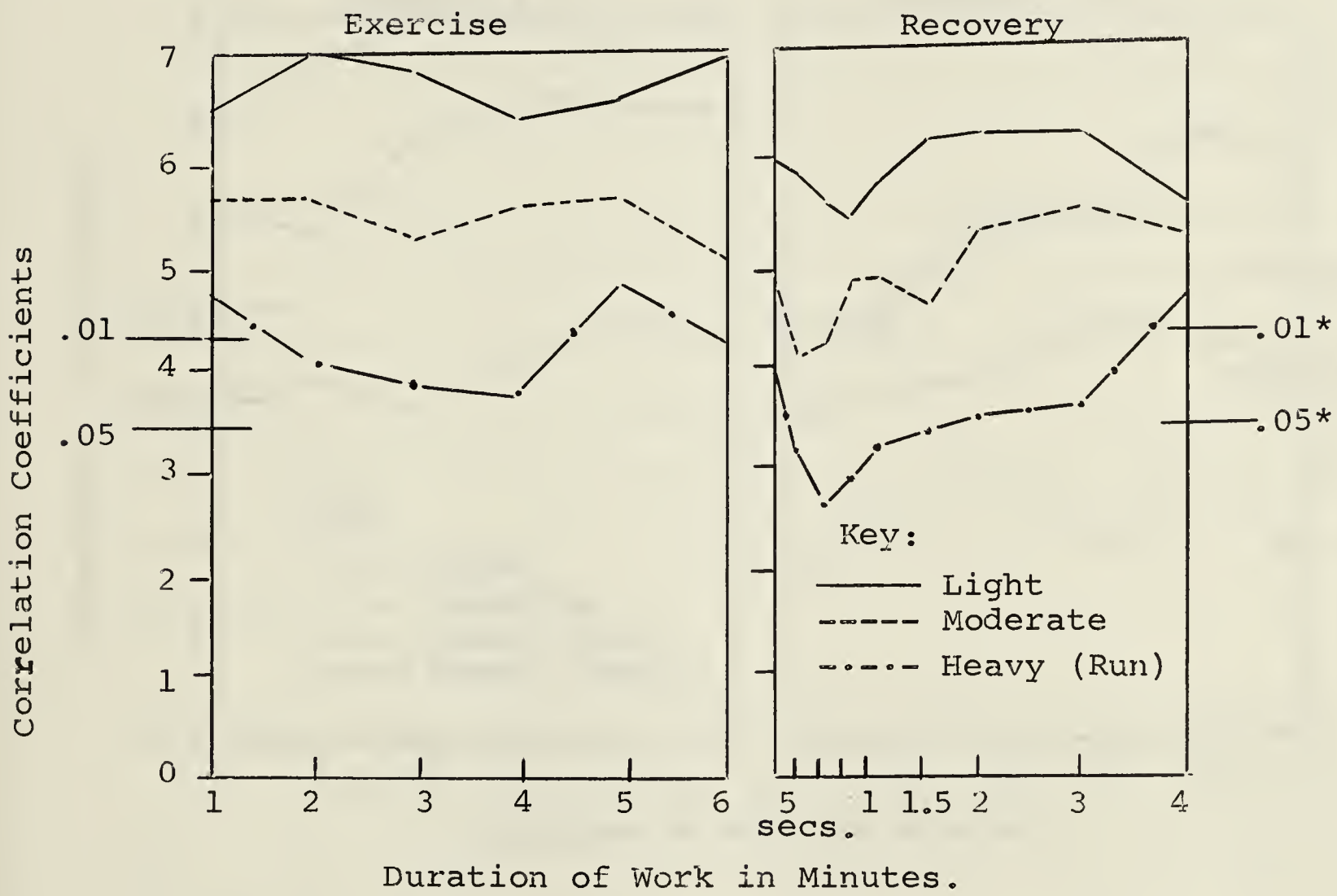
	S1	S2	S3
r at 1.00 of recovery	.31	.12	.38
1.5 of recovery	.33	.13	.37
2.00 of recovery	.34	.12	.39
3.00 of recovery	.35	.19	.37
4.00 of recovery	.46	.28	.43
Resting H-R vs. JBD Index	-.54	-.18	-.40

The difference between the correlations for the two sub-samples is quite marked. The higher correlation for Sample 3 between the Index and resting heart-rate may reflect the higher correlations between the two heart-rate counts and when the samples are combined this phenomenon may exert some influence in raising the correlation. If this reasoning is valid, assuming the homogeneity factor to be negligible, then it may be said that resting heart-rate correlates with the Index primarily because it correlates with recovery heart-rate. When the subjects all run less than 5 minutes, and the Index is dominated by time run, resting heart-rate does not correlate with this criterion of fitness. Thus resting heart-rate may be said to be correlated with this fitness criterion for some subjects only, and the correlation may be spurious.

Before attempting to draw conclusions about resting heart-rate as a predictor of fitness the patterns of correlations between resting heart-rate and heart-rate during and after exercise are worth mentioning. These are plotted against time in Figure 4 which shows the tendency for resting heart-rate to correlate more closely with lower heart-rates during and after exercise - i.e., the closer heart-rate is to resting, the higher the correlation. The change in correlations is progressive from light through to heavy work, and the pattern is quite marked.

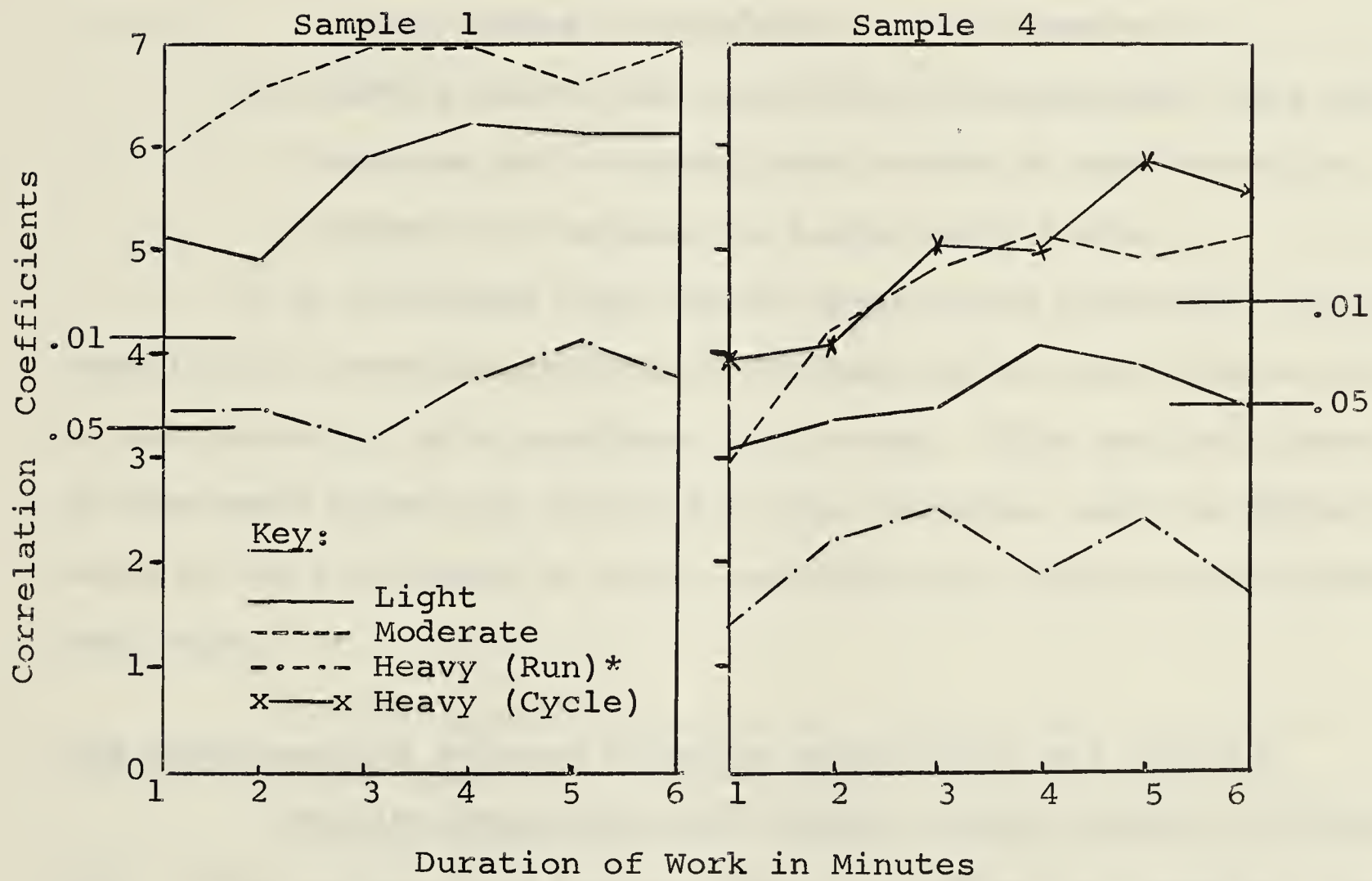
The fact that resting heart-rate correlated less and less with exercise heart-rate (which is linearly related to work level and oxygen consumption) as work intensity increased indicates a poor relationship between resting heart-rate and the organism at work. If we accept the notion that strenuous work is required to differentiate adequately between the fitness of individuals (49) it follows that resting heart-rate is a poor index for fitness.

Figure 4. The Correlations Between Resting Heart-Rate and Exercise and Recovery Heart-Rates for Sample 1 (N = 40).



* Levels of Significance.

Figure 5. The Correlations Between Exercise Heart-Rate and Maximal Oxygen Intake in Litres/min. for Sample 1 (N = 40) and Sample 4 (N = 29).



* NB. The points for heavy work (Running) represent correlations at 15, 30, and 45 seconds and at 1, 1.5, and 2 minutes of exercise. This applies to all the figures for exercise heart-rates which follow.

Summary.

(a) Resting heart-rate was significantly correlated with maximal oxygen intake in litres/min., work-done to achieve maximal oxygen intake, and the Johnson, Brouha, and Darling Fitness Index.

(b) Resting heart-rate was not correlated with maximal oxygen intake in mls/kg/min. and time-run.

(c) Resting heart-rate correlated progressively less with exercise and recovery heart-rates as heart-rate increased in response to larger work loads.

It is concluded that resting heart-rate correlates significantly with certain criteria of fitness but not with others, but is not promising as a predictor of fitness. This may be a function of the small spread of scores for this variable, and the degree to which it is influenced by other variables not directly associated with work.

The Relationships Between Exercise Heart-Rates and Fitness.

Exercise Heart-Rate and Maximal Oxygen Intake in litres/min. The correlations between these variables for Samples 1 and 4 are plotted in Figure 5.

Sample 1. During light work correlations rose from -.51 after one minute of exercise to -.61 (38%) P = .01 after six minutes. The latter was the highest for this load. There was a noticeable trend for correlations to rise with the duration of exercise, and for a plateau effect to occur from about the fourth minute of exercise. This may be associated with the relatively steady-state of

heart-rate during the later part of the exercise periods shown in Figure 2. The correlations for moderate work were consistently higher than for light work, rising from -.58 at one minute, to -.70 (49%) P = .01 at six minutes. Heavy work (running) produced correlations considerably lower than the lighter loads. The highest, after 1.5 minutes running, was -.41 (17%) P = .05.

Sample 4. The correlations for this group showed similar trends to those described above. Once again moderate work was associated with correlations consistently higher than light work. Duration of work clearly had some effect upon the correlations which tended to rise up to the third or fourth minutes of work and then level off. This was not the case with the heavy cycling load in which the correlations rose fairly steadily. The extra load was associated with slightly better correlations than the moderate load during the last two minutes of work. Correlations for heavy work (running) were low and not significant.

It is concluded that heart-rate during light and moderate cycling was correlated significantly with maximal oxygen intake in litres/min, almost reaching a high level of correlation, -.71, in moderate work. There is evidence that the predictive value of heart-rate (from cycling) increases with work level, and to some extent with duration of work.

Heart-rate during heavy work (running) was poorly correlated with maximal oxygen intake. This may reflect on or more of the following factors:

(a) In heavy work resulting in a rapid increase of energy expenditure, heart-rate is influenced by other factors in addition to aerobic capacity.

(b) In work leading to heart-rates approaching maximal the spread of scores (heart-rates) is comparatively small. During moderate work for Sample 1 with mean heart-rates rising from 141 to 158 b.p.m., the standard deviations were from 13.4 to 15.8. During heavy work (running) for this sample, with mean heart-rates rising from 163 to 190 in two minutes, the standard deviation fell rapidly from 14.2 after 15 seconds running, to 7.6 after 1.5 minutes when the highest correlation (0.41) occurred.

(c) The lower correlations for running may reflect task specificity, chiefly associated with the different functions played by body-weight in running and cycling. This could result in a different ranking of heart-rate for these work conditions. This possibility gains some support from the correlation between heart-rate after six minutes cycling and heart-rate after forty-five seconds running for Sample 4. The mean heart-rates at these points were virtually the same, being 173 (SD 11.0) and 174 (SD 7.6) b.p.m. respectively. The correlation was .29 and not significant.

It seems likely that these three factors, work intensity, spread of scores, and task specificity, may combine to produce low

correlations between heart-rate in heavy work (running) and maximal oxygen intake as compared with correlations for submaximal work in cycling.

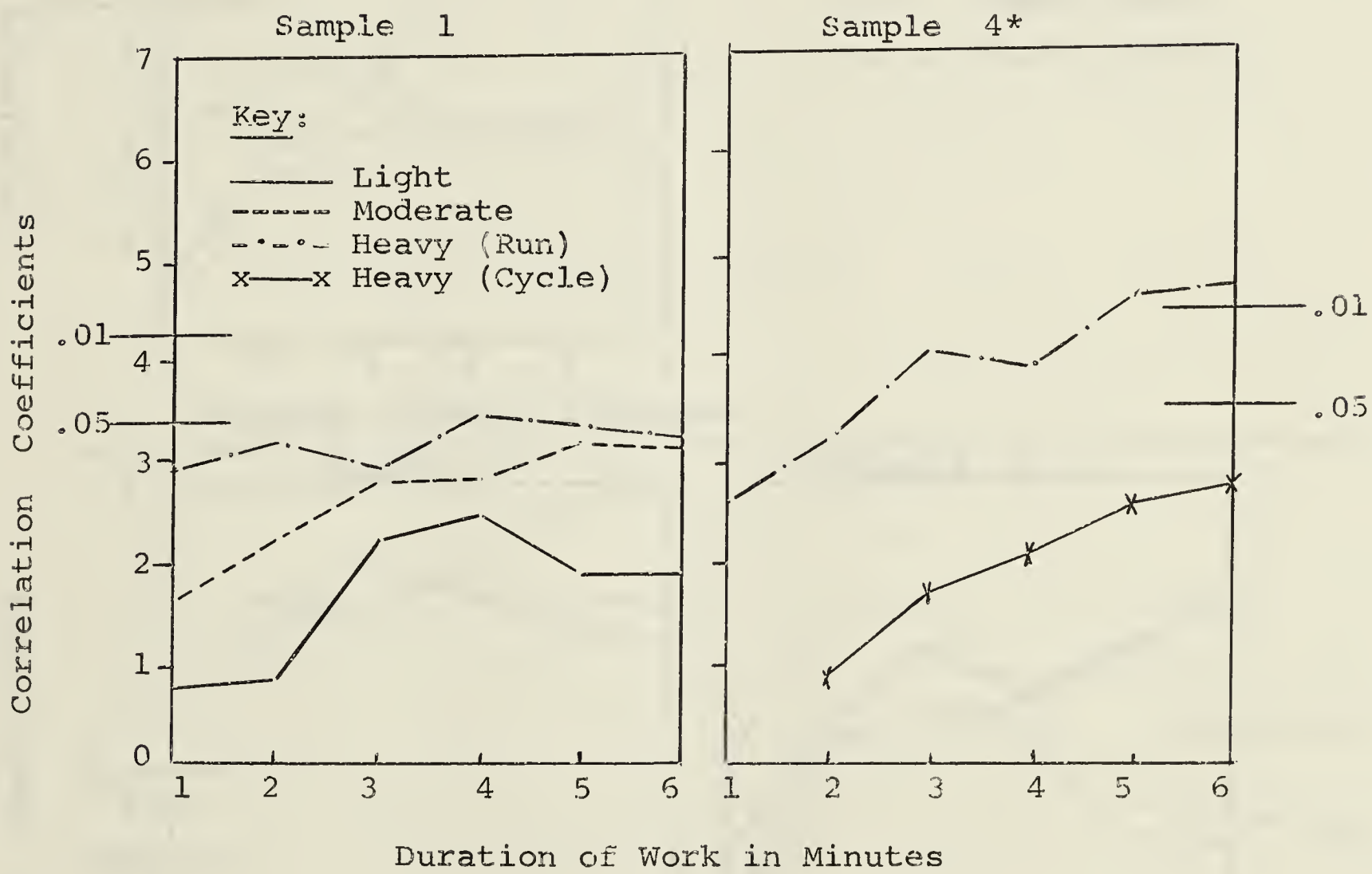
Exercise Heart-Rate and Maximal Oxygen Intake in mls/kg/min.

Sample 1. The correlation between exercise heart-rate and maximal oxygen intake in mls/kg/min. are shown in Figure 6. The only significant one was -.35 (12%) P = .05 after one minute of heavy work (running). Moderate work was correlated more closely with this measure than light work. The difference between the correlations for moderate and heavy work (running) was small.

Sample 4. Heavy work (running) produced the highest correlations, rising to -.47 (22%) P = .01 after 2 minutes.

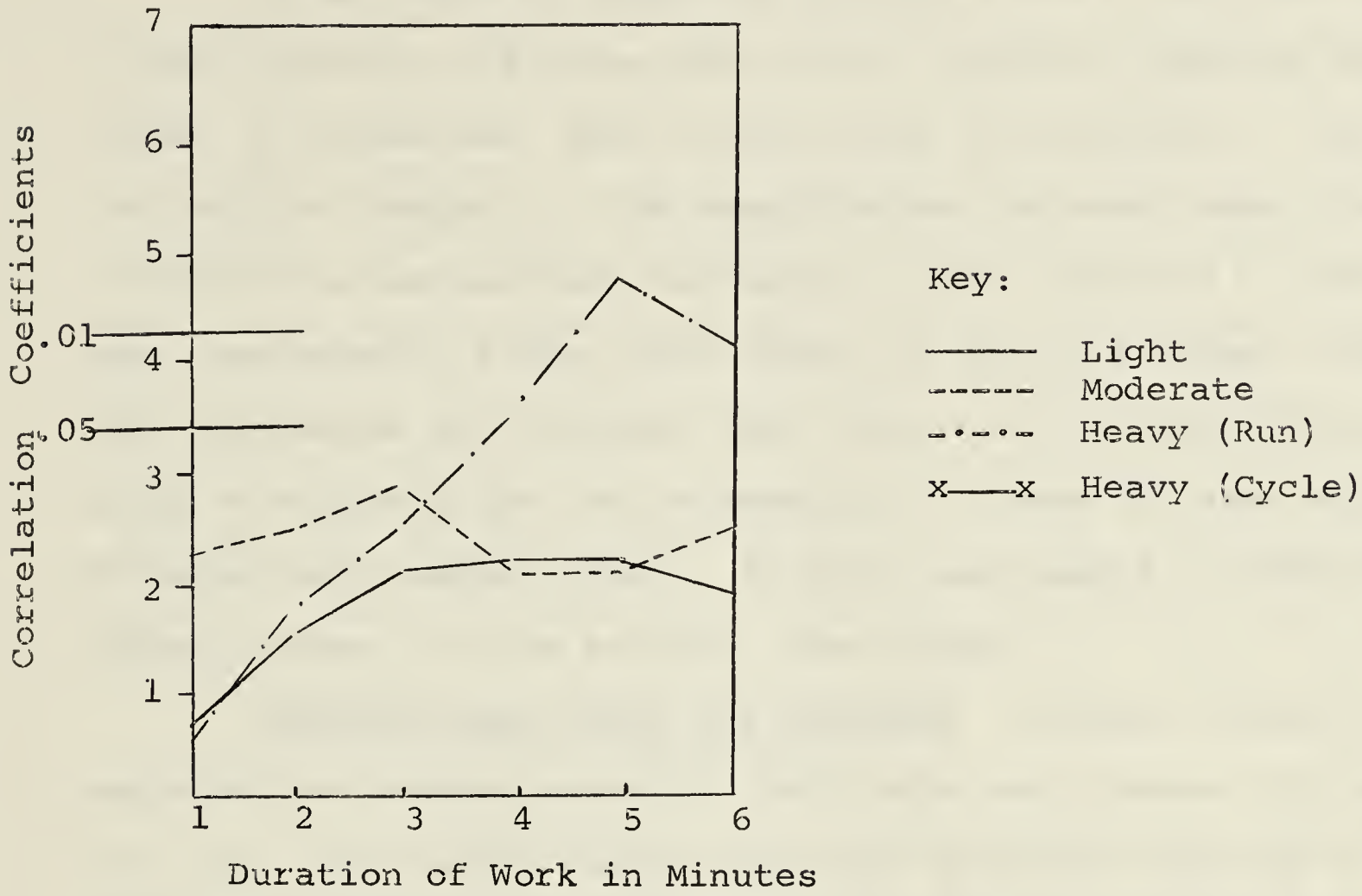
The tendency for both duration of work and work level to be associated with higher correlations was evident for both samples. The superiority of heavy work (running) correlations even those associated with cycling may once again reflect of task specificity. Heart-rates of course, were ranked in the same order as for the correlations with maximal oxygen intake in litres/min., with the ranking of maximal oxygen intake reorganized relative to body-weight. Clearly heart-rate in running was more a function of maximal oxygen intake in mls/kg/min., than heart-rate in cycling. However, the relationship between heart-rate and maximal oxygen intake relative to body-weight, even in heavy running, was not impressive. This may reflect high work intensity and restricted spread of scores, and it is possible that running at a lower intensity would result in higher correlations between heart-rate and this fitness measure.

Figure 6. Correlations Between Exercise Heart-Rates and Maximal Oxygen Intake in Mls/kg/min. for Sample 1 (N = 40), and Sample 4 (N = 29).



* For Sample 4 Light and Moderate Work are not included since some of the correlations were positive and some negative.

Figure 7. Correlations Between Exercise Heart-Rates and Time-Run for Sample 2 (N = 22).



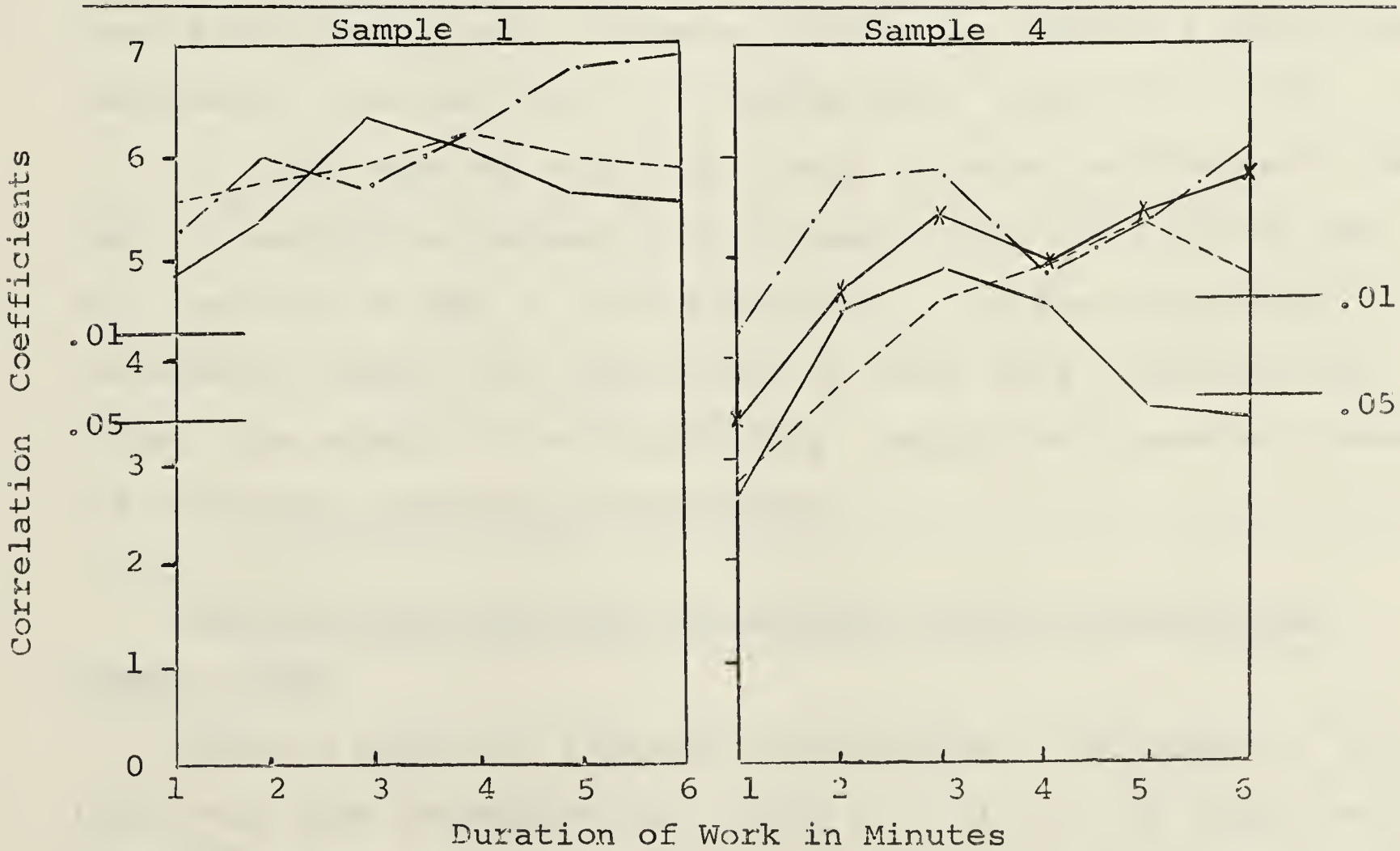


Figure 8. Correlations Between Exercise Heart-Rates and the JBD Index for Sample 1 (N = 40) and Sample 4 (N = 29).

It is noted by comparing Figures 5 and 6 that for Sample 1 heart-rates at all three work-levels reflected maximal oxygen intake in litres/min. more closely than in mls/kg/min. This did not hold for Sample 4. The exceptionwas for heavy work (running) in which the correlations for oxygen intake relative to body-weight were consistently higher than those for absolute oxygen intake. This phenomenon may indicate that factors which differentiate one group of subjects are not necessarily the same as those which differentiate another group. In this case Sample 4 comprised fitter persons, on the average, than Sample 1.

Exercise Heart-Rate and Time-Run. Figure 7 shows the correlations between exercise heart-rate and time-run for Sample 2 (N = 22). Heart-rate during light and moderate work was not correlated significantly with time-run. For heavy running a significant correlation occurred after 1.5 minutes work, being -.47 (22%) P = .05, which was the only significant correlation obtained. The lack of correlation between cycling heart-rates and time-run may be a function in part of task specificity, and the unpromising correlation pattern for heart-rates in heavy work (running) may reflect the effects of work-intensity, restricted spread of scores, and relatively high group homogeneity.

Exercise Heart-Rate and the Johnson, Brouha, and Darling Fitness Index.

Figure 8 shows the relevant correlations. For Sample 1, for light work they ranged from -.47 (22%) P = .01 to -.63 (40%) P = .01; for moderate work they ranged from -.53 (28%) P = .01 to -61 (31%) P = .01; for heavy work (running) they ranged from -.50 (25%)

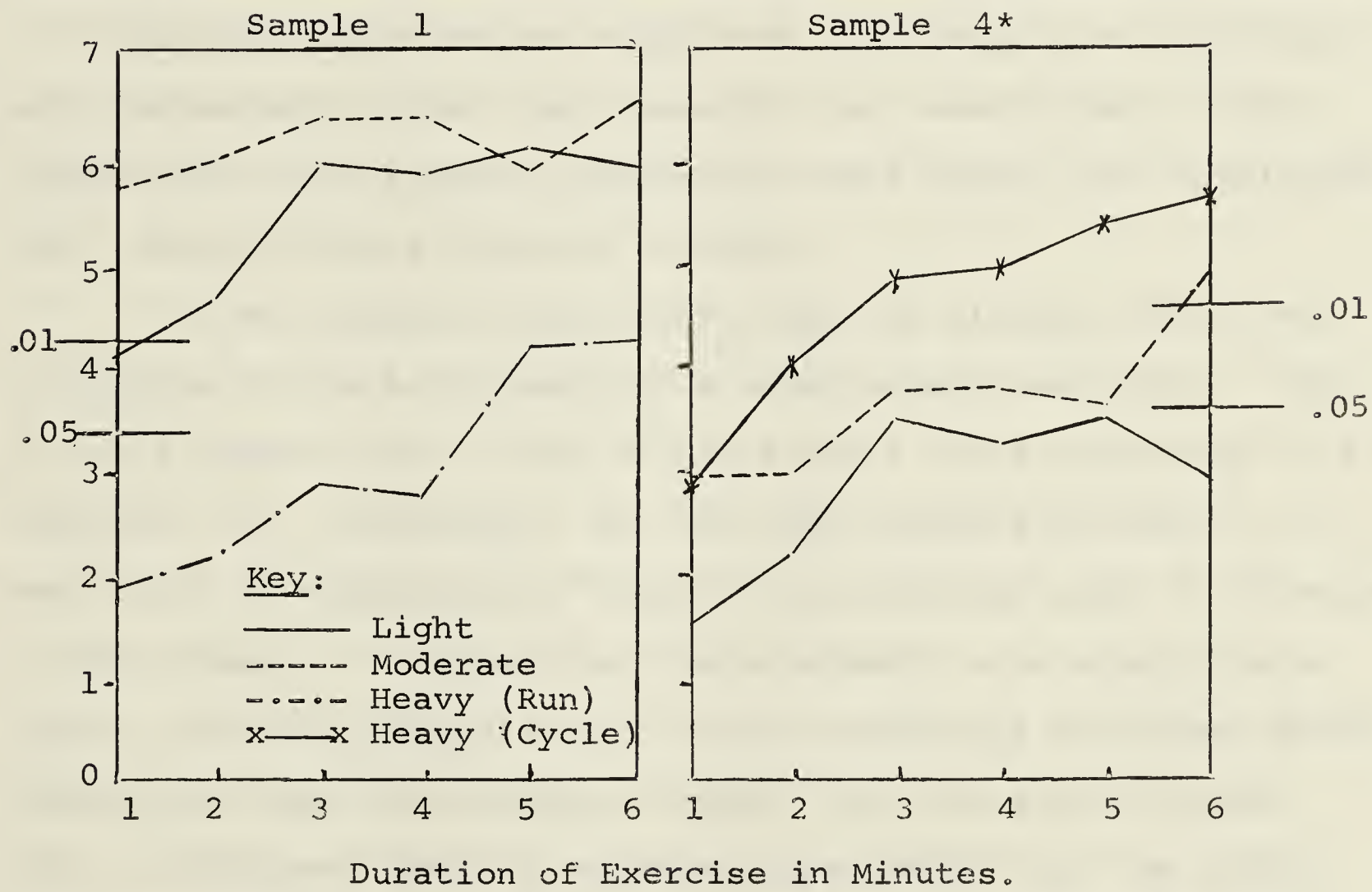
P = .01 to -.69 (48%) P = .01. Some of these correlations are quite high, approaching the 'high' category, and all the others fall in the 'moderate' class. However, these correlations may be influenced, in a manner similar to the correlation between resting heart-rate and the index, by the presence of heart-rate counts in both variables resulting in spuriously high relationships. The correlations between final exercise heart-rate in heavy work (running) and recovery heart-rates at 1 minute, 1.5 minutes, 2 minutes, 3 and 4 minutes after exercise (these approximate the 30 second heart-rate counts which figure in the index) were .51, .47, .52, .48, and .50 respectively.

It is interesting to note that compared with the other correlation patterns so far observed, the differences between correlations from one load to another are far less marked and less consistent. This may show that the spurious factor described above remained fairly constant from one work-load to another, a phenomenon which casts some doubt on the value of the correlations obtained. The pattern of correlations for Sample 4, in Figure 9, is similar to that for Sample 1.

Exercise Heart-Rate and Work-Done to Achieve Maximal Oxygen Intake.

The correlations between these variables are illustrated in Figure 9. During light work correlations ranged from -.40 (16%) P = .05 after 1 minute to -.58 (34%) P = .01 after 6 minutes, for Sample 1. In moderate work the correlations for the first and sixth minutes were -.56 and -.66 (44%) P = .01 respectively. The

Figure 9. Correlations Between Exercise Heart-Rates and Work-Done to Reach Maximal Oxygen Intake for Sample 1 (N = 40), and Sample 4 (N = 29).



* For Sample 4 Heavy Work (Running) is not included since some were positive and some were negative.

'plateau' effect observed from the third minute is very similar to the one previously referred to in connection with the correlations between heart-rate and maximal oxygen intake in litres/min. (Figure 5).

In both Samples there was a tendency for correlations to increase with work load. This was particularly evident for Sample 4 in which the correlations associated with heavy work (cycling) were considerably higher than those for the lesser loads. These correlations rose steadily through the work period, not displaying the 'plateau' effect referred to above.

It was suggested previously that the plateau effect was a function of the achievement of a steady-state heart-rate. This is quite logical, since if one of the factors being correlated is a constant (i.e., work-done), and the other remains the same (i.e., heart-rate in steady-state) then the correlations might be expected to stay steady. It seems that the attainment of a steady-state, judging from the present data, is not necessarily the prime factor underlying close relationships between heart-rate and fitness. This is indicated from the repeated observation that the higher correlations are generally associated with the higher cycling loads for Sample 4, and Figure 2 shows clearly that the higher the load the smaller is the tendency for heart-rate to reach a steady-state. The significance of these findings is discussed in a later section of this chapter.

For Sample 1 the correlations between heart-rate in heavy work (running) and work-done reached a significant level

only after 1.5 minutes of work, the highest correlation being -.42 (18%) P = .01 after 2 minutes. It is possible that at this point, approximately, the organism adapted to the highly intense work with heart-rate achieving a more consistent relationship with energy expenditure. Up to this point it is also possible that the mechanical efficiency of subjects varied considerably with this factor, in addition to work ability, affecting heart-rates. Particularly for those subjects not well practiced on the treadmill at high speeds, the start of the Johnson, Brouha, and Darling test is something of a shock. Some subjects take considerable time before settling into an even stride. At high rates of work fluctuations in stride require a relatively great and rapid adjustment which could well cause large fluctuations in heart-rate. These problems are much less crucial at lower work-loads, where mechanical efficiency is more easily maintained at a constant level, and adjustments to work are more easily effected.

It may be observed from Figure 7 that the correlations between heart-rate in heavy work (running), and time-run, the other fitness criterion expressed in terms of work (or at least directly proportional to work-done) also reached their highest after 1.5 minutes.

Summary. The main findings concerning exercise heart-rate as a correlate of fitness were as follows:

(a) heart-rate during light and moderate work was significantly related to maximal oxygen intake in litres/min., the Johnson, Brouha, and Darling Fitness Index,

and work done to achieve maximal oxygen intake. The correlations fell in the 'moderate' category, that is between .45 (20%) and .71 (50%).

(b) correlations tended to rise with duration of work (cycling) and with increased work load, as shown by the consistent superiority of correlations associated with moderate work over those associated with light work. The extra cycling load for Sample 4 emphasised this tendency, showing it to operate to a high level of heart-rate for that sample.

(c) heart-rate during light and moderate work was not significantly correlated with maximal oxygen intake in mls/kg/min. and time-run.

(d) heart-rate during heavy work (running) correlated significantly with maximal oxygen intake in litres/min., (though only for the more heterogeneous Sample 1) with time run, the Johnson, Brouha, and Darling Fitness Index, and work-done (only for Sample 1).

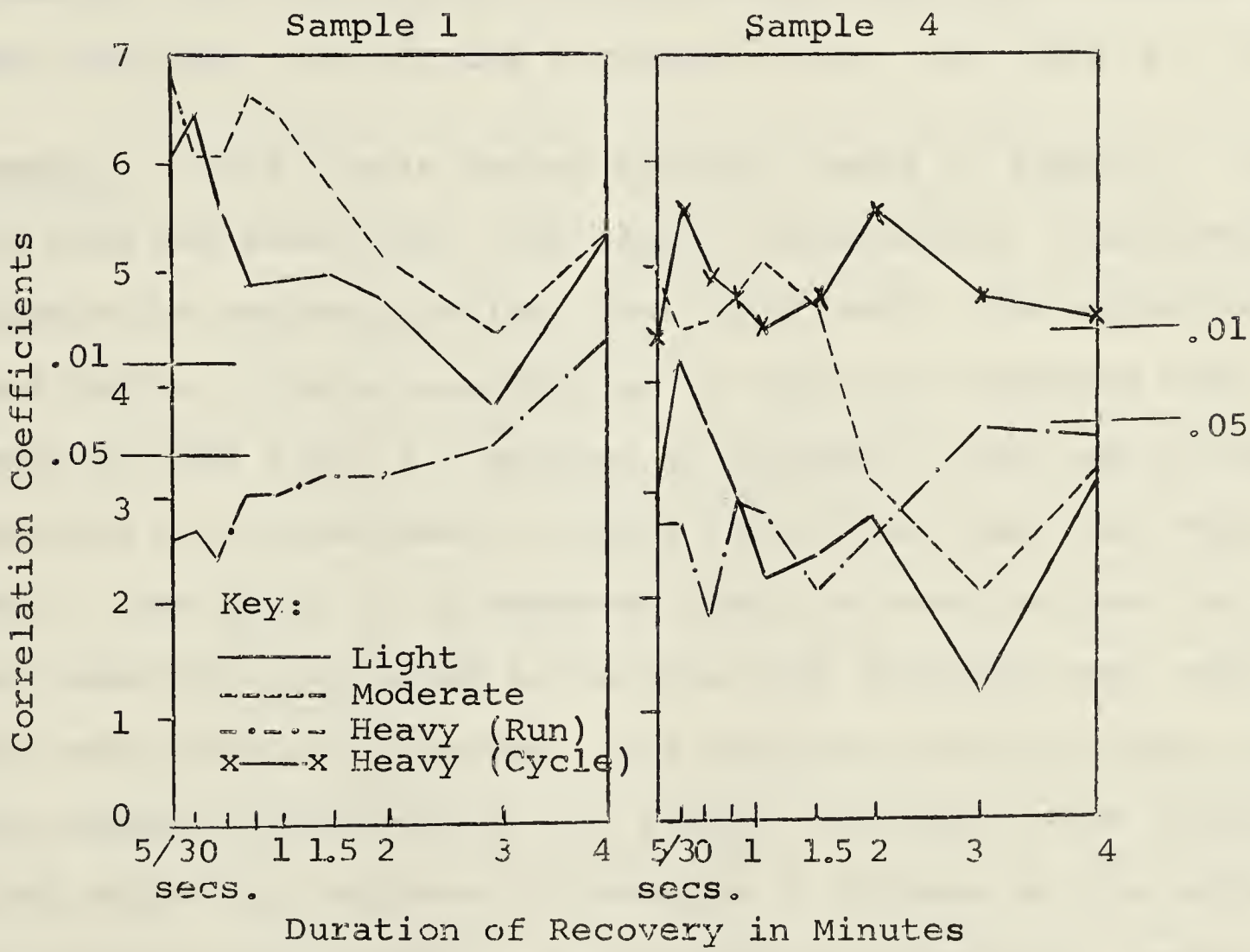
(e) the relationships between heart-rate and the fitness criteria used here were not the same for Samples 1 and 4.

Relationships Between Recovery Heart-Rate and Fitness Criterion Measures.

Recovery Heart-Rate and Maximal Oxygen Intake in Litres/min.

The correlations between these variables are shown in Figure 10.

Figure 10. Correlations Between Recovery Heart-Rates and Maximal Oxygen Intake in Litres/min. for Samples 1 (N = 46) and 4 (N = 29).



Sample 1. For light and moderate work the highest correlations obtained were shortly after exercise, tending to fall as the duration of rest extended. For light work the correlations associated with heart-rates 5 and 15 seconds after exercise were -.60 (36%) and -.64 (41%) P = .01 respectively. In contrast, for heavy running, correlations tended to rise as duration of recovery extended. The correlation corresponding with the 5 second count was -.26 (NS) and with the 4 minute count -.44 (19%) P = .01.

Sample 4. This sample showed similar trends to Sample 1. Moderate work was associated with higher correlations, consistently through the recovery period, than light work. The extra cycling load led to correlations similar to those for moderate work, at least for the first 1.5 minutes of recovery, after which they remained at a considerably higher level than those for moderate work. Once again it is observed that the correlations for light and moderate work tended to decline with extended rest, while those for heavy running increased. The different relationships for the two samples between curves for lighter and heavy work (running) loads again may indicate differences in fitness of the subjects constituting the groups. It seems that for Sample 4, heart-rate after light work was of relatively less value, and heart-rate after heavy work (running) of more value in differentiating subjects according to this fitness criterion.

The fact that the correlation curves for cycling and running heart-rates slopedin converse directions is noteworthy. It may indicate the different physiological effects resulting from

what is primarily aerobic work on the one hand, and what is largely anaerobic work on the other, with correspondingly different effects upon heart-rate. For the lighter loads (aerobic) heart-rate shortly after exercise reflects maximal oxygen capacity the most, declining thereafter and reflecting more and more the physiological characteristics of the resting state. For heavy work (running, anaerobic) there may be a three-phase relationship between heart-rate and the physiological state of the organism:

(a) immediately after exercise, heart-rate reflects things other than or in addition to aerobic capacity, including anaerobic metabolism. Hence a low relationship with aerobic capacity.

(b) following some degree of recovery, as the oxygen debt associated with anaerobic metabolism is repaid, heart-rate becomes increasingly a function of aerobic capacity. Hence an increase in the relationship with aerobic capacity.

(c) with further recovery, heart-rate tends to reflect more and more the physiological conditions of the resting state. This being true, correlations in this phase would start to fall.

Phase (a) is presumably associated with heart-rates close to or at a maximal level, phase (b) with heart-rate considerably lower and changing more slowly, and phase (c) with a lower level still, and changing yet more slowly.

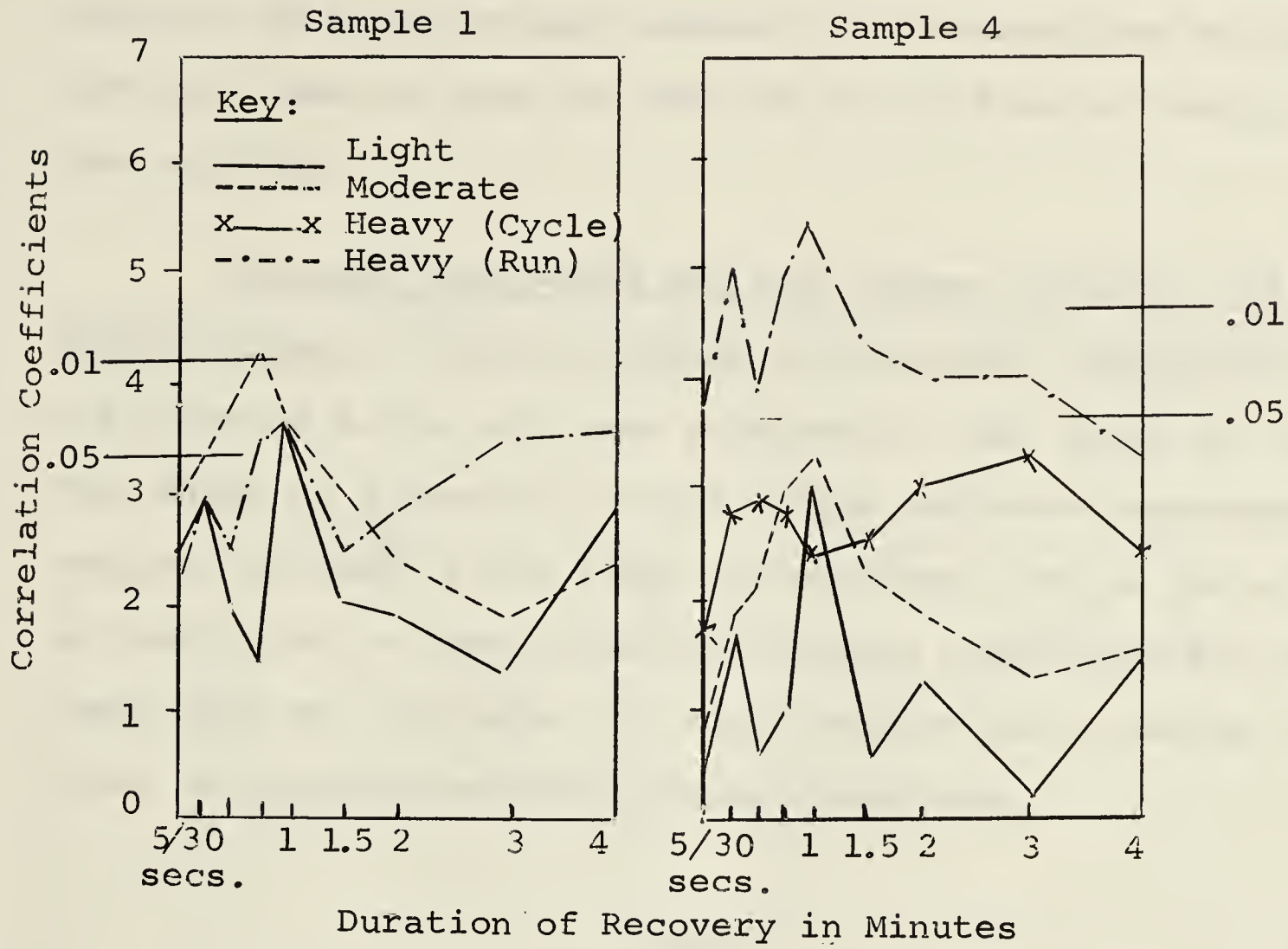
Recovery Heart-Rate and Maximal Oxygen Intake in mls/kg/min. The correlations between these variables are shows in Figure 11. For Sample 1 it is observed that the highest correlation, -.43 (18%) P = .01 was associated with moderate work. However, there was little difference in the correlations from one work load to the other, and none appears to be profitable. For Sample 4 the early recovery heart-rates after heavy work (running) gave rise to some moderate correlations, the highest being -.55 (30%) P = .01 at one minute of recovery. This was much higher than the correlations associated with the three cycling work loads.

Recovery Heart-Rate and Time-Run. Figure 12 shows the correlations for Sample 2 (N = 22). All were non-significant, the highest being -.31 (10%) NS immediately after moderate work. Correlations for heavy work (running) gave no consistent pattern, some being positive and some negative.

Clearly there was no systematic relationship between whatever heart-rate reflects as a result of sub-maximal cycling and time-run, and this may indicate the specificity of the work tasks involved.

There was likewise no systematic relationship between heart-rate recovery following maximal work and time-run. In this case the heart-rates were obtained after the run with which they were correlated, and they therefore reflect the specific intensity of the work, and the specific type of work involved. Thus there is strong justification for the conclusion that recovery heart-rate after maximal work is not related to time-run.

Figure 11. Correlations Between Recovery Heart-Rates and Maximal Oxygen Intake in mls.min. for Sample 1 (N = 40) and Sample 4 (N = 29).



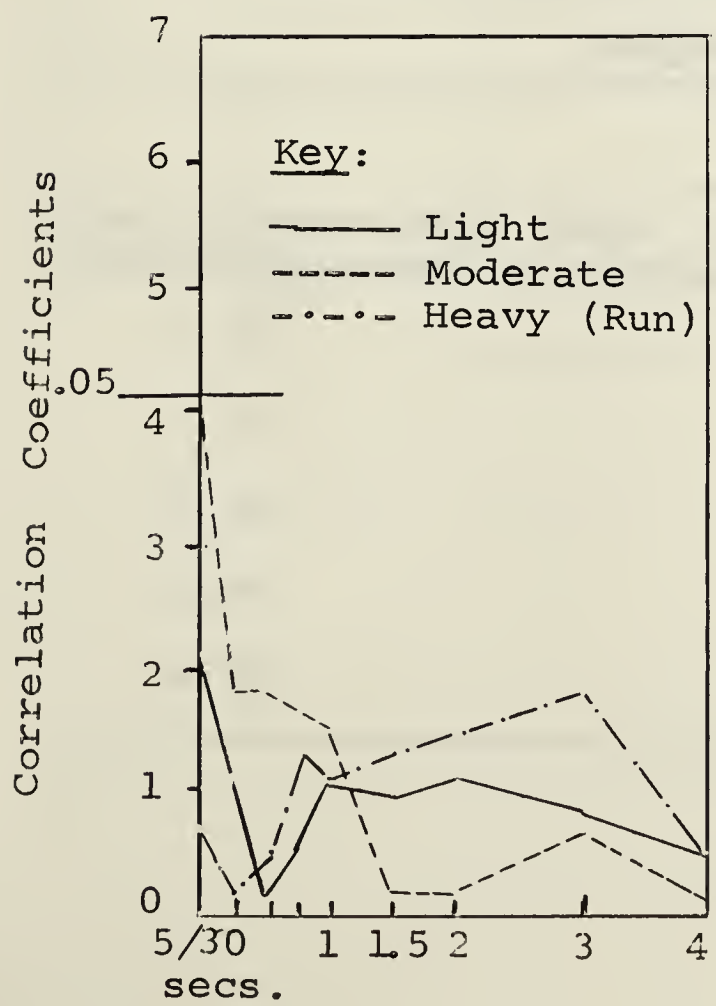


Figure 12. Correlations Between Recovery Heart-Rates and Time-Run for Sample 2 (N = 22).

It is important to emphasise that higher correlations might be obtained between recovery heart-rates after sub-maximal work and time-run when the work is in the form of running rather than cycling.

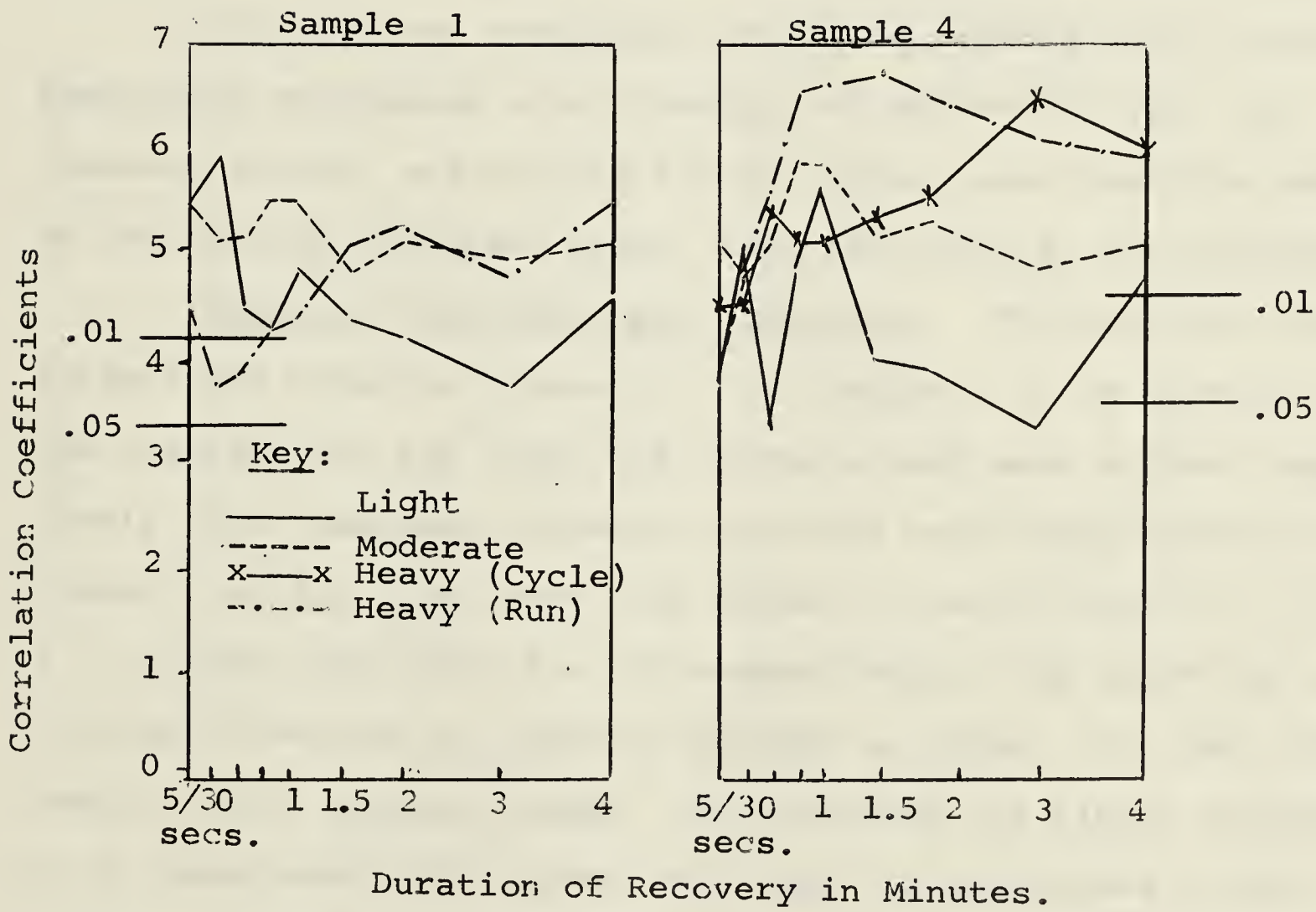
Recovery Heart-Rate and the Johnson, Brouha, and Darling Fitness Index. Figure 13 shows the relevant correlations and they are observed to be much more substantial than those for time-run. This might be a function of the larger and more heterogeneous samples involved in the index correlations, but on the other hand, as postulated in connection with resting heart-rate and exercise heart-rate vs. the Index, it might reflect the presence of heart-rates in both the variables being correlated.

TABLE V

Correlations Between Recovery Heart-Rates and the Johnson, Brouha, and Darling Fitness Index, for Samples 1, 2, 3, and 4

Time of Heart-Rate Count	S1 (N = 40)	S2 (N = 22)	S3 (N = 18)	S4 (N = 29)
1.00	-.44	-.11	-.91	-.66
1.30	-.51	-.20	-.96	-.67
2.00	-.53	-.19	-.95	-.65
3.00	-.45	-.06	-.94	-.61
4.00	-.56	-.18	-.89	-.59

Figure 13. Correlations Between Recovery Heart-Rates and the Johnson, Brouha, and Darling Fitness Index.



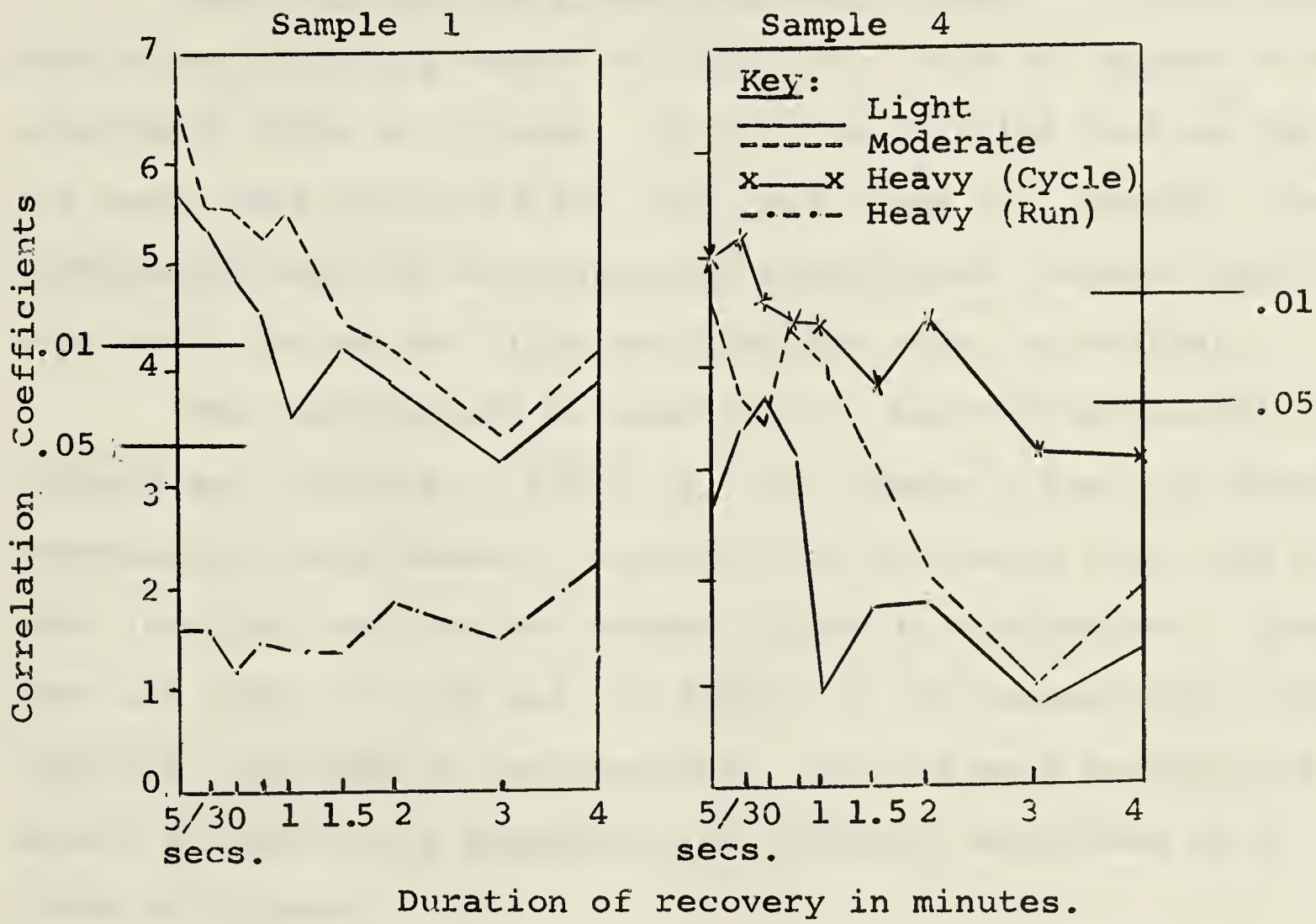
The differing influence of heart-rate upon correlations from one Sample to another, depending upon the nature of the sample, is obvious from Table V. For Sample 3 the correlations were highest, as one might expect since these subjects were differentiated in terms of recovery heart-rate. The correlations were lowest for Sample 2, in which subjects were differentiated by time-run with heart-rate having a negligible effect. The combination of these two Samples to form Sample 1 resulted in moderate correlations.

Although the conclusion cannot be avoided that recovery heart-rate correlated significantly and moderately with the Johnson, Brouha, and Darling Fitness Index, some doubt is cast, by the factors discussed above, upon the value of the correlations.

Recovery Heart-Rate and Work-Done. The relevant correlations are shown in Figure 14. For Sample 1 it is observed that the correlations for light and moderate work were highest immediately after exercise, those for moderate work being consistently higher than for light work, the highest of each being -.65 (42%) P = .01 and -.56 (31%) P = .01 respectively. The trend for correlations to decline as recovery extends is noted. The data for Sample 4 show similar trends. The tendency for higher correlations to be associated with higher work loads is emphasised by the superior correlations for the extra cycling work load over the lighter cycling loads, and once again correlations decline as recovery extends.

Heart-rate recovery from heavy work (running) was not significantly correlated with work-done. This is not surprising, considering the specific aspects of the work tasks giving rise

Figure 14. Correlations Between Recovery Rates and Work-Done to Reach Maximal Oxygen Intake for Sample 1 (N = 40) and Sample 4 (N = 29).



to the factors being correlated. This finding is of interest considering the high correlation of .79 between work-done and time-run. It suggests that although fitness for one task and the other have elements in common, these elements are not necessarily reflected in heart-rate during heavy work (running).

Rate of Heart-Rate Recovery and Fitness. It has already been shown that this aspect of heart-rate does not appear to be a profitable index of fitness. It will be recalled that as far as the means were concerned for 'fit' and 'less fit' samples, the differences were not statistically significant, whether heart-rates were quite low as for light and moderate work, or maximal.

The correlations between rate of heart-rate recovery and fitness are included in Table VI. For Sample 1 the only significant correlations were between recovery rate following light and heavy work (running) and maximal oxygen intake in mls/kgm/min. These were .34 (12%) P = .05 and .33 (11%) P = .05 respectively, falling into the low class of correlations. For the main Sample this aspect of heart-rate appeared to be virtually worthless as an index of fitness.

For Sample 4 the picture was slightly different. While recovery rate was not significantly related to maximal oxygen intake in litres/min., or to work-done, it was moderately correlated with maximal oxygen intake in mls/kg/min. and moderately correlated with the Fitness Index, for moderate work and heavy work (running). The correlations with the Fitness Index may be spurious owing to the presence of heart-rates in both variables.

TABLE VI

Correlations Between Rate of Heart-Rate Recovery and Fitness for Samples 1 (N = 40) and Sample 4 (N = 22)

Fitness Criterion		Work-Load			
		Light Work	Moderate Work	Heavy Work Running	Heavy Work Cycling
Maximal Oxygen Intake in litres/min.	Sample 1	-.16	.25	.22	-
	Sample 4	-.13	.26	.21	.13
Maximal Oxygen Intake in mls/kg/min.	Sample 1	.34*	.30	.33*	
	Sample 4	.52**	.45*	.50**	.12
Time-run	Sample 2	-.14	-.13	-.18	-
Johnson, Brouha, and Darling Fitness Index.	Sample 1	-.02	.26	.32	-
	Sample 4	.35	.48**	.63**	.21
Work done to achieve Maximal oxygen intake.	Sample 1	-.32	.08	.10	-
	Sample 4	-.23	.10	.07	.14

NB: Correlations for time-run concern Sample 2 (N = 22).

* Significant at the 5% level.

** Significant at the 1% level.

General Trends Observed for Correlations Between Heart-Rate and Fitness Criteria

Heart-Rates Associated with Cycling. The following trends were apparent:

(a) Correlations for exercise heart-rates increased with work load, and with the duration of exercise for a given load.

(b) Correlations for recovery heart-rates increased with work load and declined as duration of recovery extended.

These findings support the suggestion by Johnson et al (49) that heavy exercise tends to reveal inter-individual differences in fitness better than light exercise. The primary explanation they offered for this phenomenon is that heavy exercise results in a wider spread of arithmetic differences between fitness scores. With respect to exercise heart-rates this explanation was not substantiated in the present study, which showed a definite tendency for spread of heart-rates, in terms of standard deviations, to decline as work load and heart-rate increased. Recovery heart-rates were associated with increased spread of scores as work load increased, showing some measure of agreement with Johnson et al (49). However, the highest correlations were not associated with the highest standard deviations which occurred from about the 30th second of recovery onwards. It will be recalled that the correlations started to decline from about the 15th second of recovery.

An alternative explanation is required for the superior correlations between heart-rates and fitness at higher levels of

work, because it appears that these correlations occur in spite of smaller spread of scores. It is suggested that as work rate increases a truer sampling of the physiological aspects of the organism associated with work is achieved, and the variance associated with factors such as emotion is progressively eliminated. The same explanation may apply to the observations, reported in the review of literature, that the reliability of heart-rates increases with work load. The influence of spread of scores on the differentiation of levels of fitness is no doubt of some importance, but it seems that between the lowest spreads of heart-rate, that is in the resting state and in very intense exercise such as the Johnson, Brouha, and Darling test, there is a broad range of work loads which provide adequate arithmetic differences of heart-rates.

Steady-State Heart-Rate. It is shown in Figure 2 that as work load in cycling increased the tendency for Samples 1 and 4 to reach a steady-state heart-rate decreased. Since the highest correlations were associated with the higher work loads it appears that the reaching of a steady-state heart-rate is not essential to differentiate levels of fitness according to the criteria used in this study.

However, for a given work load the highest correlations occurred when heart-rate tended towards a steady-state. This may indicate that for lower levels of work the achievement of a steady-state marks the truer sampling of fitness referred to above.

Heart-rates Associated with Running. Heart-rates associated with running were in general less closely correlated with fitness than heart-rates associated with cycling. No strict comparison may be drawn between the correlations resulting from the different work tasks, owing to their specific nature. However, it is suggested that the smaller correlations for heart-rates in running may reflect the smaller spread of heart-rates resulting from intense work, together with the involvement of anaerobic work to a greater extent than in cycling.

Correlations Between Heart-Rates and the Johnson, Brouha, and Darling Fitness Index. It was observed that the correlations involving the Index tended to be more uniform from one work load to another than those involving the other fitness criteria. This is clearly seen in Appendix E, and may indicate a fairly constant spurious factor in the correlations. It was suggested that this factor was the presence of heart-rates, known to be correlated, in both 'sides' of the correlations.

The Relative Value of Different Counts of Heart-Rate in Predicting Fitness. Table VII compares the correlations for resting, exercise, recovery and maximal heart-rates, and rate of heart-rate recovery. The correlations for exercise heart-rate are for the final heart-rate recorded at each work load, since these tended to be the highest, and for recovery heart-rate they are for the counts at the 5th and 15th seconds of recovery for the same reason. With respect to heavy work (running) the correlations for the 4th minute of recovery are included since these tended to be higher than for earlier recovery counts.

TABLE VII

Selected Correlations* Between Heart-Rates and Criterion Fitness Measures for Sample 1 (N = 40), and Sample 4 (N = 29)

Fitness criterion measures	Resting Heart Rate	Light Work			Moderate Work			Heavy Work Running 2 mins.	Maximal Heart-Rate and Recov.			
		6 mins. ex.	5 secs. recov.	15 secs. recov.	6 mins. ex.	5 secs. recov.	15 secs. recov.		Max.	5 secs. recov.	15 secs. recov.	4 mins. recov.
SAMPLE 1:												
Maximal Oxygen Intake in Litres per min.	-49	(-62	*** -60)	-65	(-70	-69)	-62	-37	-22	-26	-27	-44
Maximal Oxygen Intake in mls/ kg/min.	-25	-18	-25	-31	-31	-30	-33	-32	-22	-22	-30	-25
Time-Run**	-15	-18	-21	-12	-24	-31	-18	-40	00	-09	-03	05
The Johnson, Brouha and Darling Fitness Index	-54	(-55	-54)	-60	(-57	-54)	-51	-69	-36	-45	-37	-55
Work-Done to Achieve Maximal Oxygen Intake	-43	(-58	-56)	-63	(-66	-65)	-55	-42	-08	-16	-16	-22
SAMPLE 4:												
Maximal Oxygen Intake in Litres per min.	-31	-35	-27	-42	-52	-50	-44	-17	-19	-27	-27	-35
Maximal Oxygen Intake in mls/ kg/min.	-27	06	-01	-18	-13	-09	-22	-47	-34	-38	-51	-33
The Johnson, Brouha and Darling Fitness Index	-41	34	-37	-51	-47	-40	-48	-60	-37	-51	-47	-55
Work-Done to Achieve Maximal Oxygen Intake	-12	-28	-26	-34	-49	-46	-37	-12	05	-01	-06	06

TABLE VII (Continued)

Selected Correlations* Between Heart-Rates and Criterion Fitness Measures for Sample 1 (N = 40), and Sample 4 (N = 29)

Fitness criterion measures	Heavy Work (Cycling 6 mins. ex.	5 secs. recov.	15 secs. recov.	Light Work	Moderate Work	Heavy Work (Running)	Heavy Work (Cycling)	Maximal Heart-Rate,**
SAMPLE 1:								
Maximal Oxygen Intake in Litres per min.				-16	25	22		07
Maximal Oxygen Intake in mls/kg/min.				34	30	33		29
Time-Run**				-14	-13	-18		00
The Johnson, Brouha and Darling Fitness Index				-02	26	32		11
Work Done to Achieve Maximal Oxygen Intake				-32	08	10		03
SAMPLE 4:								
Maximal Oxygen Intake in Litres per min.	-55	-44	-56	-13	26	21	13	
Maximal Oxygen Intake in mls/kg/min.	-26	-17	-51	52	45	50	12	
The Johnson, Brouha, and Darling Fitness Index	-57	-44	-46	35	48	63	21	
Work-Done to Achieve Maximal Oxygen Intake	-55	-50	-52	-23	10	07	14	

* Decimal points omitted.
** For Sample 2 (N = 22)
*** Differences between r's in parentheses not significant.

Levels of Significance: Sample 1 (N = 40), r = .33 sign. at 5% level; r = .42 sign. at 1% level. Sample 2 (N = 22), r = .41 sign. at 5% level; r = .53 sign. at 1% level. Sample 4 (N = 29), r = .36 sign. at 5% level; r = .46 sign. at 1% level.

Maximal Heart-Rate. The correlations for maximal heart-rate were uniformly low for all samples thus confirming the findings of Taylor (73) and Boas (20). It included that this aspect of heart-rate is of no value in predicting fitness,

Rate of Heart-Rate Recovery. There were no useful relationships between rate of heart-rate recovery and fitness for Sample 1. Some correlations were slightly higher for Sample 4 but still showed no great promise. These findings, together with the finding that the means of recovery rate for 'fit' and 'less fit' subjects were not significantly different suggest that rate of heart-rate recovery is of little value in predicting fitness. In regard to recovery from maximal or near maximal heart-rates this is in agreement with the findings of Kramer (55) Cogswell et al (28) and Knehr et al (53). The finding that recovery rate after submaximal work leading to lower heart-rates was equally unprofitable conflicts with the suggestion of Knehr et al (53) that recovery rate from submaximal work may be of use in predicting fitness.

These findings recall the comment by Astrand (13) that rates of recovery may be used to distinguish changes of fitness in one individual, but vary too greatly from one individual to another to adequately distinguish inter-individual differences.

Resting Heart-Rate. This aspect of heart-rate correlated less closely with the fitness criteria than exercise and recovery heart-rates. In view of this finding and the probability that it is subject to severe fluctuation leading to unreliable results,

it is concluded that resting heart-rate is of little value in predicting physical fitness.

Exercise and Recovery Heart-Rates. Table VIII gives the correlations between the final counts of exercise heart-rate and recovery heart-rates up to the first minute of recovery for Samples 1 and 4. It is observed that high correlations were obtained between final exercise heart-rates and heart-rates at the 5th and 15th seconds of recovery. These results confirm the findings of Cotton (30) and Le Blanc (56).

Reference to Table VII shows that the correlations with the fitness criteria were very similar for final exercise and initial recovery heart-rates. This was particularly marked for Sample 1 and the differences between correlations for given loads (in parentheses) were not statistically significant, suggesting that the two aspects of heart-rate represent the same physiological state of the organism to a high degree.

Taylor (74) supported by Janda (48) and Billings et al (18) suggested that to evaluate physical fitness adequately, the responses of the cardiovascular-respiratory system should be recorded during rather than after exercise. This appears to be true when considering rate of recovery and isolated recovery heart-rates recorded when heart-rate has started to decline appreciably. However, it does not seem to apply to heart-rates counted immediately after exercise. It is therefore concluded that heart-rate counted immediately after exercise may predict fitness as accurately as final exercise heart-rate.

TABLE VIII

Correlations Between Final Exercise Heart-Rates for Different Work-Loads and Heart-Rates During the First Minute of Recovery, for Sample 1 (N = 40) and Sample 4 (N = 29)

Final Exercise Heart-Rates	Recovery Heart-Rates				
	5 secs.	15 secs.	30 secs.	45 secs.	1 min.
Sample 1:					
Light Work	.93	.86	.86	.84	.82
Moderate Work	.96	.91	.89	.90	.92
Heavy Work (Running)	.91	.80	.78	.70	.64
Sample 4:					
Light Work	.87	.77	.82	.80	.73
Moderate Work	.94	.82	.79	.83	.86
Heavy Work (Cycling)	.90	.88	.84	.84	.83
Heavy Work (Running)	.90	.85	.81	.72	.69

This finding is of practical importance since post-exercise heart-rate is more conveniently recorded than heart-rate during exercise.

The Prediction of Different Fitness Criteria from Heart-Rates. Table IX includes the correlations for Sample 2 for final exercise heart-rates and initial recovery heart-rates vs. the fitness criteria. The correlations associated with the 4th minute of recovery are included with respect to heavy work (running). Sample 2 is used to permit the inclusion of time-run, the direct criterion, in the comparison.

Cycling. It is observed that for cycling work-loads the highest correlations were between heart-rate and maximal oxygen intake in litres/minute; the second highest were with work done; the third highest with the Fitness Index (possibly spuruous); the fourth highest with time-run; and the lowest with maximal oxygen intake in mls/kg/min. The differences form a consistent pattern, which is confirmed, with the exception of time-run, by the equivalent correlations for Sample 1 shown in Table VII.

This hierarchy of correlations is what might be expected. Since heart-rate is a physiological variable directly concerned with aerobic metabolism one would expect it be more closely related to aerobic capacity than to the other criteria.

The second highest correlations, associated with work-done, involve work performance and variance is possibly affected by muscular strength, local muscular endurance, and cycling efficiency. These additional factors might be expected to lead

TABLE IX

Selected Correlations Between Heart-Rates and Fitness Criteria for Sample 2 (N = 22) and Sample 3 (N = 18)

Fitness Criteria	Heart-Rates					
	Exercise*			Recovery**		
	Light	Moderate	Heavy (running)	Light	Moderate	Heavy (running)
Sample 2:						
Maximal Oxygen Intake in litres/min.	-.61	-.67	-.08	-.57	-.67	-.43
Work-Done to Reach Maximal Oxygen Intake	-.51	-.57	-.39	-.54	-.61	-.24
The Johnson, Brouha, and Darling Fitness Index	-.33	-.40	-.47	-.35	-.48	-.18
Time-Run	-.18	-.24	-.40	-.21	-.31	.05
Maximal Oxygen Intake in mls/kg/min.	.08	-.09	.09	-.02	-.15	.01

* Final heart-rate counts.

** Initial (5 sec.) recovery counts for light and moderate work, final (4 min.) recovery count for heavy work (running).

TABLE IX (Continued)

Selected Correlations Between Heart-Rates and Fitness Criteria for Sample 2 (N = 22) and Sample 3 (N = 18)

	Heart-Rates					
	Exercise*			Recovery**		
Fitness Criteria	Light	Moderate	Heavy (running)	Light	Moderate	Heavy (running)
Sample 3:						
Maximal Oxygen Intake in litres/min.	-.24	-.47	-.09	-.24	-.51	-.11
Work-Done to Reach Maximal Oxygen Intake	-.34	-.53	.07	-.25	-.52	.21
The Johnson Brouha, and Darling Fitness Index	-.03	-.23	-.54	-.10	-.15	-.89
Maximal Oxygen Intake in mls/kg/min.	.37	.05	-.21	.23	.05	-.06

to lower correlations than for maximal oxygen intake vs. heart-rate. However, the fact that work-done was primarily regulated by maximal oxygen intake may explain the relative position of these correlations.

The third highest correlations, as mentioned already, may be spurious to some extent.

The fourth highest correlations, involving time-run no doubt reflect the influence of variables such as motivation and anaerobic metabolism associated with intense work taken to exhaustion. A purely cardiovascular variable, such as heart-rate, cannot be expected to predict maximal work performance, according to Montoye (63). The findings of this study tend to confirm this statement.

Maximal oxygen intake in mls/kg/min. was correlated least well with heart-rates, and it was shown earlier that this expression of maximal oxygen intake correlated less well with the other fitness criteria than maximal oxygen intake in litres/min. It appears that the relative expression of this variable is of little value as a criterion of fitness, at least when measured by a cycling test. It is suggested that the expression of absolute oxygen intake as a proportion of a factor (body-weight) which gives rise to absolute oxygen intake is confusing, and its meaning not clear.

Running. For heavy running the highest correlations for exercise heart-rates were with the Index, with those for time-run and work-done being virtually the same. The former correlations

may be spurious, and the similarity of the other two (confirmed in Sample 1, Table VII) amplify the correlation reported earlier of .79 between time-run and work-done.

Differences in Correlations for Different Samples. Reference was made earlier to the observation that the correlations between heart-rate and fitness were not the same for subject groups of different fitness. This is clearly shown where the correlations for Sample 2 and Sample 3 are compared in Table IX.

The Influence of Body-Weight. It was indicated in Table II that body-weight was significantly correlated with the fitness criteria associated with cycling (maximal oxygen intake in litres/min. and mls/kg/min, and work-done to reach maximal oxygen intake) and was not correlated with the criteria associated with running (time-run, and the Johnson, Brouha, and Darling Fitness Index). Appendix D includes the correlations between heart-rates and body-weight, and it is observed once again that only those associated with cycling were significant. Table X shows the effect of the partialling out of body-weight from the correlations involving heart-rates and maximal oxygen intake in litres/min., work-done to reach maximal oxygen intake, and the Johnson, Brouha, and Darling Fitness Index. It is observed that where body-weight was correlated with both variables (i.e., heart-rate and fitness) partial correlation resulted in a diminished correlation coefficent. This was not the case where body-weight was correlated with only one of the variables, and the correlations remained virtually unchanged or increased.

TABLE X

Correlations Between Exercise Heart-Rate and Maximal Oxygen Intake in litres/min., Work-Done to Achieve Maximal Oxygen Intake, and the Johnson, Brouha, and Darling Fitness Index, with Body-Weight Partialled Out*, for Sample 1

	Work-Load		
	Light	Moderate	Heavy (Running)
Maximal Oxygen Intake in litres/min.	-.62 (-.48)	-.70 (-.60)	-.37 (-.38)
Work-Done to Achieve Maximal Oxygen Intake	-.58 (-.47)	-.66 (-.58)	-.42 (-.43)
The Johnson, Brouha, and Darling Fitness Index	-.55 (-.63)	-.57 (-.63)	-.69 (-.69)

* The original r's are above the partial r's which are in parentheses.

These findings emphasise the specificity of cycling and running previously referred to, and particularly the different influence of body-weight.

It might be argued that in some ways the use of partial correlations was not appropriate to the present study. First, in work-tasks of many kinds body-weight contributes decisively to inter-individual differences in performance. Examples of such tasks are rowing, canoeing, weight-lifting (including occupational tasks) coal-shovelling and the like, in which the criterion of performance is absolute work performed per unit time, rather than work performed in relation to body-weight. Thus body-weight, in some situations, and this applies to stationary cycling against fixed loads, is an important aspect of fitness for work, and in assessing the correlation between one fitness variable

and another for predictive purposes, attempts to eliminate its influence are not necessary. On the other hand, it might be thought that partial correlation analysis served a useful purpose in demonstrating the effect of body-weight upon the correlations obtained. However, it is felt that this purpose was served to only a limited degree. In holding body-weight constant by partialling it out of correlation coefficients the resulting relationship represents a hypothetical situation which in fact rarely, if ever, exists in practice. Furthermore, body-weight almost certainly constitutes a factor (in fact it constitutes many anatomical and physiological factors) which interact dynamically with other factors contributing to fitness, and it seems unlikely that a statistical procedure is adequate to the task of eliminating its influence. It is suggested that at best partial correlations should be regarded only as a preliminary indication of the degree to which a dynamic aspect of fitness (body-weight) affects the relationship between two fitness variables with which it is known to interact. Special experimental situations are required to examine such a problem adequately, and in the present case the adjustment of work-load in cycling to body-weight might be useful.

SUMMARY AND CONCLUSIONS

The main purpose of this study was to compare the extent to which resting, exercise, and recovery heart-rates are related to physical fitness defined as the ability to perform prolonged heavy work. The criteria of fitness and the associated measures of fitness were as follows:

1. 'Direct' fitness (time-run for subjects running less than five minutes in the Johnson, Brouha, and Darling Test).
2. 'Indirect' fitness (Maximal Oxygen Intake as measured by the Astrand Bicycle Ergometer Test of Maximal Oxygen Intake).
3. 'Ratio' fitness (the Johnson, Brouha, and Darling Fitness Index).
4. 'Ratio' fitness (work-done to reach Maximal Oxygen Intake).

Subsidiary purposes were to study:

1. The relationship between 'direct' and 'indirect' fitness.
2. The relationship between Maximal Oxygen Intake and work-done to reach it.
3. The relationship between time-run and work-done to reach Maximal Oxygen Intake.

Data were analysed for forty male subjects aged 17 to 35 comprising students and staff of the University of Alberta, and soldiers from Griesbach Barracks, Edmonton.

Exercise and recovery heart-rates associated with different work loads were measured during the Astrand Bicycle Ergometer Test of Maximal Oxygen Intake, and the Johnson, Brouha, and Darling Test. Resting heart-rate was measured during a

period of 20 to 30 minutes of rest in a lying position.

Mean values and standard deviations were computed for all variables and each variable was correlated with all other variables.

The following conclusions were reached with respect to the results obtained:

1. 'Fit' and 'Less-fit' Subjects

(a) Groups of subjects, classified as 'fit' and 'less-fit' according to a 'direct' measure of fitness, tend to differ significantly in 'indirect' and 'ratio' measures of fitness.

(b) 'Fit' and 'Less-fit' subjects, as described above, tend to differ significantly in resting heart-rate, exercise heart-rate during submaximal work, and recovery heart-rate counted shortly after submaximal work. They tend not to differ significantly in maximal or near maximal heart-rate, recovery heart-rate shortly after maximal work, and rate of heart-rate recovery during the first minutes following work ranging in intensity from light to heavy.

2. The Spread of Scores for Heart-Rate

(a) Spread of scores, in terms of standard deviations tends to decline for exercise heart-rate as work load increases.

(b) Recovery heart-rate provides a spread of scores which increases rapidly from the start to about the second minute of the recovery period, and in association with increased submaximal work load.

(c) Recovery heart-rate provides a greater spread of scores for a given work load than exercise heart-rate.

3. Relationships Between Different Fitness Criteria

(a) Maximal Oxygen Intake ('indirect' fitness) is significantly and moderately correlated with time-run ('direct' fitness) in work which exhausts all subjects in less than five minutes.

(b) Maximal Oxygen Intake is significantly and highly correlated with the work-done to reach it when both measures are obtained from the same work task.

(c) Work-done to reach Maximal Oxygen Intake obtained from stationary cycling against fixed loads and time-run in work which exhausts all subjects within five minutes are significantly and highly correlated.

4. The Johnson, Brouha, and Darling Fitness Index

(a) Subjects who complete five minutes running are differentiated by heart-rates counted at intervals from 1 to 5 minutes after exercise.

(b) Subjects who fail to complete five minutes running are differentiated mainly by time-run.

(c) The two ways of differentiating the fitness of subjects may represent a basic weakness in the Johnson, Brouha, and Darling Fitness Index as a measure of fitness.

5. The Relationship Between Heart-Rates and Fitness

(a) The relationship between exercise heart-rate (in stationary cycling against fixed submaximal loads with work periods of 6 minutes) and fitness tends to increase with work

load, and to decline as duration of recovery extends.

(c) The achievement of a steady state heart-rate during submaximal work is not associated with the highest correlations between heart-rate and physical fitness.

(d) Maximal heart-rate (180+ b.p.m.) is poorly correlated with physical fitness, as is recovery heart-rate from work leading to maximal heart-rate.

(e) Rate of heart-rate recovery during the first minute following work ranging in intensity from light to very intense is poorly correlated with physical fitness.

(f) Resting heart-rate is significantly correlated with physical fitness according to certain criteria, but for a given criterion is less closely related to fitness than exercise and recovery heart-rates associated with sub-maximal work.

(g) There is a high correlation between heart-rate at the end of exercise and recovery heart-rate counted shortly after exercise (5 seconds).

(h) Exercise heart-rate and recovery heart-rate counted shortly after exercise (5 seconds) are significantly and moderately correlated with certain criteria of physical fitness to a degree which does not differ significantly.

(i) Heart-rate associated with submaximal work of relatively long duration in stationary cycling tends to be more closely related to aerobic capacity (a physiological measure of fitness), than to time-run, to exhaustion in work of short duration, and work-done to reach Maximal Oxygen Intake (measures involving work output).

(j) Factors contributing to inter-individual differences in fitness are not necessarily the same for subjects of different fitness grouped according to a 'direct' criterion of fitness.

6. The Influence of Body-Weight

(a) Body-weight is significantly correlated with exercise and recovery heart-rates associated with cycling against fixed submaximal loads.

(b) There is a considerable difference between the functions of body-weight in stationary cycling and in treadmill running.

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APPENDIX A

AGE, HEIGHT AND WEIGHT OF SUBJECTS.

Age, Height, and Weight of Subjects

Subject	Age	Height (Inches)	Weight (Kilograms)
1	23	68	70.08
2	20	69.5	80.85
3	19	71	81.65
4	23	78	86.73
5	25	70	73.94
6	33	73	77.34
7	24	71	78.02
8	25	68.5	77.34
9	30	71	73.94
10	23	73	77.11
11	26	69.5	76.20
12	29	74	80.29
13	22	70.5	77.11
14	18	69	63.05
15	22	72	76.66
16	25	71.75	83.46
17	23	70	77.11
18	24	67.5	70.76
19	17	69	65.00
20	29	67	70.31
21	21	69	76.20
22	21	70	78.74
23	18	72.5	67.13
24	21	69	69.40
25	20	70.25	72.58
26	26	69	80.92
27	17	67.5	68.03
28	22	69	66.23
29	19	73	87.00
30	19	65	53.98
31	17	70	92.53
32	21	67.75	67.13
33	17	66	62.37
34	20	72	82.33
35	25	70.5	79.38

Age, Height, and Weight of Subjects (Continued)

Subject	Age	Height (Inches)	Weight (Kilograms)
36	25	70.25	77.11
37	17	68.5	64.41
38	23	72	75.07
39	21	67	66.90
40	21	72	71.21

APPENDIX B

RAW SCORES FOR FITNESS CRITERION MEASURES AND HEART-RATES

Subjects	Max. VO_2 litres/ min.	Max. VO_2 mls/kg. per min.	Work Done at Max. VO_2	Rest H-R	JBD Index	Max. H-R	Exercise Heart-Rate, 600 kpm/min. 1 min.	2 min.	3 min.	4 min.	5 min.	6 min.
1	2.560	36.41	1500	64	43.3	184	115	122	129	136	136	143
2	3.587	43.45	14450	64	48.2	195	113	120	125	127	125	123
3	2.510	40.24	3600	82	24.3	191	134	143	148	145	143	148
4	2.920	40.23	3900	80	46.7	200	132	143	148	150	148	150
5	3.559	55.26	4875	72	38.7	200	117	122	122	120	122	120
6	2.903	45.07	12200	80	63.4	191	118	127	125	122	125	130
7	3.106	47.78	10950	68	52.8	191	132	134	136	136	138	141
8	3.470	39.89	12450	60	57.3	187	115	122	118	118	118	118
9	3.123	33.75	5850	64	24.2	191	115	114	117	123	122	118
10	2.787	41.52	7200	80	39.4	195	129	136	141	141	141	143
11	3.218	45.19	15000	70	68.5	195	113	113	118	117	118	114
12	2.620	40.68	0	88	27.0	195	129	143	155	155	155	155
13	3.164	34.36	7200	68	35.0	187	95	100	105	106	102	98
14	2.732	42.42	4500	72	33.6	209	148	117	158	167	173	173
15	3.448	42.23	16275	72	59.4	200	125	129	129	136	130	134
16	3.478	43.02	13950	92	60.2	200	129	132	136	144	136	132
17	3.174	41.40	11100	72	47.2	195	122	125	129	134	134	130
18	3.717	44.54	16200	60	69.7	187	113	110	114	105	114	114
19	3.273	39.75	10700	63	39.6	200	106	120	123	118	120	127
20	3.068	41.49	11950	62	50.2	184	127	130	141	145	125	132
21	3.488	51.27	9540	76	52.0	191	138	141	148	150	148	145
22	3.652	47.93	13700	54	54.3	200	111	117	123	123	115	127

Subjects	Max. VO_2 litres/ min.	Max. VO_2 mls/kg. per min.	Work Done at Max. VO_2	Rest H-R	JBD Index	Max. H-R	Exercise Heart-Rate, 600 kpm/min. 1 min.	2 min.	3 min.	4 min.	5 min.	6 min.
23	3.498	40.33	16200	61	82.9	195	106	100	108	108	105	115
24	3.582	50.62	14700	52	83.8	187	102	106	108	111	107	114
25	3.053	45.64	7200	70	77.3	195	118	118	123	127	127	127
26	3.262	44.12	7200	56	79.8	184	103	108	106	113	114	111
27	3.885	56.72	18900	58	91.5	176	129	129	132	130	134	132
28	3.699	49.27	21600	64	66.1	204	114	120	114	117	122	123
29	3.732	48.25	13950	56	102.7	191	102	99	99	110	106	113
30	3.912	50.73	16100	64	86.7	184	98	103	108	88	102	97
31	3.305	47.32	12823	50	76.5	200	101	107	101	115	106	111
32	4.061	50.19	16200	59	78.5	195	105	106	110	114	113	111
33	4.078	52.89	16200	66	82.0	187	122	132	130	127	134	134
34	3.598	51.34	22200	68	76.1	184	115	117	103	122	110	120
35	3.426	51.17	10950	56	83.8	184	113	107	110	115	113	110
36	3.899	50.56	22050	66	75.4	195	108	110	108	113	110	113
37	4.541	47.11	25950	60	69.8	191	97	100	98	99	90	95
38	3.861	50.07	22200	58	90.4	187	107	102	105	106	103	106
39	3.030	42.28	18262	66	64.9	204	120	118	115	120	122	115
40	3.697	55.25	3900	72	75.8	187	118	130	125	127	132	132

Subjects	Recovery Heart-Rate, 600 kpm/min.									Recov. Rate	Exercise Heart-Rate, 900 kpm/min.					
	5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.30	2	3	4	600 kpm.	1 min.	2 min.	3 min.	4 min.	5 min.	6 min.
1	141	129	115	110	106	103	110	96	100	37	145	161	173	176	180	184
2	103	105	88	80	85	83	80	83	80	38	132	141	145	153	148	150
3	145	138	123	144	113	107	100	99	102	35	153	158	167	170	164	167
4	143	130	117	110	107	100	103	106	99	43	148	158	161	161	155	161
5	110	94	80	70	60	61	76	69	63	60	123	132	132	141	138	143
6	102	108	93	80	85	80	84	93	89	45	134	143	138	148	145	150
7	130	122	117	118	91	100	99	85	105	50	145	150	153	161	161	161
8	118	111	101	93	96	87	83	87	91	22	130	136	134	138	136	138
9	106	95	84	66	71	67	61	75	69	47	136	138	138	141	145	145
10	141	134	132	110	103	106	102	103	105	40	153	155	161	167	161	167
11	108	102	93	80	76	82	81	83	71	38	123	134	136	150	145	145
12	148	134	120	117	120	117	107	97	106	35	164	173	176	184	184	187
13	100	85	79	86	83	77	66	68	68	15	117	122	125	129	136	134
14	158	150	148	138	134	136	114	111	114	39	176	187	187	191	191	195
15	125	99	108	113	113	81	105	100	99	21	141	141	145	150	150	150
16	125	118	122	107	102	106	113	102	100	30	141	145	145	150	155	150
17	130	120	122	102	99	103	103	101	88	31	138	150	155	161	167	167
18	115	107	84	73	76	76	70	64	72	38	136	132	138	148	148	150
19	122	111	97	106	100	77	81	83	83	27	138	141	150	155	164	164
20	125	111	108	96	102	93	95	83	108	30	136	153	153	153	161	161
21	141	139	138	122	102	106	110	110	101	43	150	155	161	161	164	167
22	122	117	103	105	90	81	87	99	90	37	136	141	143	148	158	150

Subjects	Recovery Heart-Rate, 600 kpm/min.									Recov. Rate	Exercise Heart-Rate, 900 kpm/min.					
	5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.30	2	3	4	600 kpm.	1 min.	2 min.	3 min.	4 min.	5 min.	6 min.
23	113	87	80	69	96	87	81	88	90	19	118	127	132	134	143	148
24	107	96	96	73	73	86	75	68	69	41	125	136	138	141	148	155
25	127	114	113	102	88	89	85	85	88	39	138	145	148	150	148	167
26	105	113	105	88	80	68	67	60	59	31	122	129	143	143	145	150
27	125	87	111	102	89	96	83	94	83	43	145	145	148	153	153	150
28	115	106	89	94	87	86	83	84	77	36	127	136	148	148	145	145
29	106	87	76	69	66	66	71	83	68	47	120	130	125	129	134	130
30	100	66	76	81	59	76	66	61	69	38	125	117	118	120	114	132
31	100	88	85	81	61	60	76	65	83	50	129	130	132	138	141	138
32	105	98	97	87	79	83	81	83	78	32	123	129	123	129	132	134
33	122	111	105	99	110	96	109	102	100	24	134	143	143	148	145	153
34	114	105	89	83	87	84	66	86	73	33	134	143	138	145	155	148
35	99	82	70	72	54	53	54	65	63	56	138	136	136	138	132	136
36	111	113	84	90	83	79	87	80	75	30	136	143	138	136	138	141
37	96	80	69	65	74	61	58	65	66	21	113	117	117	122	123	127
38	102	85	91	85	78	61	64	67	69	28	118	122	127	129	130	122
39	114	110	102	89	100	91	101	83	89	15	125	134	138	138	141	143
40	123	107	98	110	100	100	93	99	89	32	143	148	155	158	161	158

Subjects	Recovery Heart-Rate, 900 kpm/min.									Recov. Rate	Exercise Heart-Rate, Heavy Running					
	5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.30	2	3	4	900 kpm.	15 secs.	30 secs.	45 secs.	1 min.	1.30	2
1	180	176	161	150	145	130	117	122	122	39	138	153	155	167	173	180
2	145	134	117	107	105	99	94	85	85	45	153	158	173	173	180	187
3	158	145	136	132	123	115	114	113	110	44	158	170	170	180	191	191
4	158	145	122	114	117	105	101	94	98	44	167	170	176	176	184	200
5	134	115	111	80	87	74	78	88	86	56	145	161	170	180	191	200
6	138	118	106	105	96	93	91	100	106	54	155	164	170	173	173	176
7	155	150	136	132	123	127	122	98	103	38	155	167	167	173	180	187
8	132	127	115	111	111	105	96	99	105	27	150	161	164	170	176	184
9	143	118	100	99	93	87	80	83	78	52	67	180	184	187	191	191
10	164	148	134	130	120	123	117	110	111	47	184	167	173	184	187	191
11	138	123	115	101	105	100	99	96	93	40	170	173	173	180	184	187
12	187	176	170	161	148	136	138	120	125	39	180	187	191	191	195	195
13	127	117	113	105	95	89	80	79	79	38	153	170	176	176	184	187
14	195	184	184	170	170	161	150	138	138	25	204	204	204	204	204	209
15	141	136	129	120	118	123	122	120	105	32	173	173	176	176	187	187
16	148	136	118	127	110	102	103	108	103	40	161	167	173	176	187	195
17	158	155	141	138	132	123	115	115	122	35	161	173	176	180	184	187
18	130	125	107	99	94	108	83	86	82	56	158	173	173	176	180	184
19	161	153	130	129	130	120	108	110	111	34	158	180	184	187	195	200
20	155	138	129	125	117	120	102	110	101	44	158	167	170	173	176	176
21	158	145	136	125	127	117	117	122	110	40	167	173	176	176	184	184
22	148	145	138	111	115	91	113	108	111	35	170	173	180	184	184	195

Subjects	Recovery Heart-Rate, 900 kpm/min.									Recov. Rate 900 kpm.	Exercise Heart-Rate, Heavy Running					
	5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.30	2	3	4		15 secs.	30 secs.	45 secs.	1 min.	1.30	2
23	145	129	118	118	105	99	93	92	91	43	136	150	158	164	170	176
24	143	127	118	111	97	89	94	83	78	58	122	134	153	155	170	176
25	164	158	127	114	134	117	110	111	100	33	153	161	167	173	180	184
26	143	130	123	107	103	97	99	86	84	47	132	148	158	161	167	173
27	150	138	125	114	96	106	91	94	106	54	153	161	161	161	170	170
28	143	132	118	102	103	118	106	110	105	42	155	176	173	180	180	184
29	129	115	105	89	83	75	69	74	74	47	158	158	173	180	184	184
30	117	93	87	74	74	80	78	80	78	58	150	153	161	161	173	173
31	132	120	98	97	98	82	83	84	83	40	153	167	173	180	184	187
32	132	125	105	102	84	96	80	92	83	50	145	167	167	173	180	187
33	148	130	122	113	117	111	110	105	100	36	141	158	161	167	170	176
34	138	117	114	102	105	92	92	96	87	43	150	161	170	173	176	184
35	132	111	91	88	76	85	54	70	63	60	148	161	170	170	173	176
36	138	132	115	111	113	100	101	106	104	28	170	180	180	184	187	187
37	114	106	87	76	76	69	78	83	68	51	161	161	167	176	176	184
38	125	118	108	93	80	83	71	86	80	42	143	150	164	167	173	173
39	141	141	129	105	110	106	94	90	88	33	167	173	173	180	184	187
40	155	143	136	107	118	117	113	107	102	40	145	158	173	170	180	184

Subjects	Recovery Heart-Rate, Heavy Running 5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.30	2	3	4	Recov. Rate Heavy Run.	Time Run	Exercise Heart-Rate, 1200 kpm/min 1 min.	2 min.	3 min.	4 min.	5 min.	6 min.
1	180	167	164	153	148	141	127	115	122	36	173						
2	200	176	176	164	155	141	130	113	105	40	177	148	164	167	173	176	180
3	184	176	161	148	138	129	122	111	123	53	90						
4	200	180	170	161	150	134	127	111	107	50	170						
5	200	180	170	150	138	125	130	111	110	62	139						
6	191	173	158	153	148	134	127	127	129	43	251	153	158	164	164	167	173
7	191	180	170	161	148	136	132	125	123	43	209	158	167	173	173	180	180
8	187	184	110	164	155	138	132	127	118	32	227	132	145	150	153	161	164
9	191	180	161	150	143	129	129	118	118	48	92						
10	191	180	173	167	161	148	136	129	122	34	178						
11	191	184	170	164	153	141	134	129	127	42	278	153	155	170	170	173	176
12	200	200	191	184	180	170	158	150	148	15	129						
13	187	180	167	158	153	138	129	122	114	34	134	132	148	155	161	167	170
14	214	214	200	204	195	184	176	167	164	14	178						
15	195	187	180	173	164	145	136	129	122	31	247	150	167	164	176	180	180
16	200	195	176	167	158	142	136	129	127	42	242	150	164	164	173	170	176
17	191	180	180	176	173	161	150	130	125	22	203	164	176	184	191	187	195
18	187	176	167	158	148	132	130	122	117	39	265						
19	204	195	176	170	161	148	132	123	122	39	160	167	184	187	187	187	195
20	182	180	167	161	161	145	136	125	127	23	209	158	161	167	167	170	173
21	191	176	170	161	155	141	136	127	129	36	207	167	173	180	180	184	187
22	191	184	180	170	161	150	145	129	125	34	229	170	176	180	184	184	184

Subjects	Recovery Heart-Rate, Heavy Running									Recov. Rate Heavy Run.	Exercise Heart-Rate, 1200 kpm/min.					
	5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.30	2	3	4		1 min.	2 min.	3 min.	4 min.	5 min.	6 min.
23	191	187	176	173	158	141	129	115	92	37						
24	184	176	164	143	134	129	127	113	102	53	148	161	161	167	167	173
25	195	187	176	167	155	138	125	123	117	40	155	167	173	180	184	187
26	180	173	167	158	155	136	129	115	107	29	145	161	167	173	176	176
27	180	164	150	130	118	114	105	110	106	58	155	161	161	164	167	173
28	204	191	187	176	173	161	153	141	136	31	155	164	158	170	173	180
29	184	173	150	125	123	86	90	88	87	68	141	145	150	155	155	158
30	180	176	155	136	134	114	118	103	111	46	143	155	150	161	164	164
31	195	187	176	170	155	132	127	127	118	45	145	155	158	161	164	167
32	191	184	176	164	158	138	122	118	113	37	141	153	155	161	161	167
33	187	173	170	158	145	132	125	113	107	42	150	155	167	167	170	173
34	184	173	164	155	150	136	132	123	120	34	153	164	167	170	173	170
35	180	173	164	155	143	127	117	107	107	41	148	158	158	161	164	170
36	191	184	170	158	155	136	125	113	112	40	148	155	161	161	167	167
37	187	180	173	170	164	158	143	132	127	28	129	138	143	141	141	148
38	180	170	161	143	136	118	111	101	102	48	138	143	148	153	148	150
39	204	195	187	180	173	167	158	148	141	31	148	153	161	164	173	173
40	187	180	167	161	158	141	138	130	120	29						

Subject	Recovery Heart-Rate, 1200 kpm/min.									Recov. Rate 1200 kpms.
	5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.30	2	3	4	
1										
2	173	161	145	134	123	115	113	105	103	57
3										
4										
5										
6	155	145	129	118	110	107	113	108	117	63
7	180	170	158	138	138	138	129	118	120	42
8	158	150	141	129	129	123	115	113	106	35
9										
10										
11	170	161	148	132	130	123	123	115	110	46
12										
13	164	158	153	138	136	120	117	113	105	34
14										
15	167	161	113	155	141	127	125	123	118	39
16	184	164	148	130	130	123	125	114	110	46
17	191	191	187	164	170	161	158	143	127	25
18										
19	187	176	167	164	150	150	132	125	125	45
20	173	161	148	145	134	122	118	115	106	39
21	180	167	153	150	150	132	134	129	115	37
22	184	176	173	164	158	148	141	127	134	26

Subject	Recovery Heart-Rate, 1200 kpm/min.									Recov. Rate 1200 kpm.
	5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.30	2	3	4	
24	173	158	136	118	115	95	105	91	91	58
25	187	180	161	150	143	132	125	114	118	44
26	176	167	164	153	145	132	123	120	117	31
27	170	155	145	129	127	122	108	110	100	46
28	173	167	161	161	145	136	125	127	113	35
29	158	153	113	113	113	96	101	85	87	45
30	155	130	102	105	102	82	98	86	100	62
31	161	155	134	127	115	106	93	98	89	52
32	170	153	141	132	120	110	107	105	102	47
33	170	158	158	143	136	129	113	100	108	37
34	167	155	141	136	138	143	130	120	111	32
35	158	155	145	134	125	113	111	100	98	35
36	170	161	143	132	132	117	103	115	110	35
37	138	125	103	85	88	78	76	87	80	58
38	145	136	122	114	114	87	103	89	114	36
39	167	164	153	145	129	123	122	110	106	44
40										

APPENDIX C

ESTIMATED HEART-RATES

Estimated Heart-Rates

The estimated heart-rates for the four subjects whose data were not complete are shown below in parentheses between the preceding and following heart-rates.

	1.5 mins.	2 mins.	3 mins.
Subject 31			
Heart-rate during recovery from moderate work	82	(83)	84

	30 secs.	45 secs.	1 min.
Subject 27			
Heart-rate during heavy work (running)	161	(161)	161

	45 secs.	1 min.	1.5 mins.
Subject 34			
Heart-rate during heavy work (running)	170	(173)	176

	3 mins.	4 mins.	5 mins.
Subject 17			
Heart-rate during moderate work	155	(161)	167

APPENDIX D

MEANS VALUES AND STANDARDS DEVIATIONS OF FITNESS CRITERION MEASURES AND HEART-RATES

Mean Values and Standard Deviations of Fitness Criterion Measures and Heart-Rates for Sample 1 (N = 40), Sample 2 (N = 22), Sample 3 (N = 18, and Sample 4 (N = 29)

Sample	MVO_2 l/min.	MVO_2 mls/kg/min.	Work Done at Max. VO_2	Resting H-R	JBD Index	Maximal H-R	Weight in kilos.	Exercise Heart-Rate, 600 kpm. 1 min.	2 min.	3 min.	4 min.	5 min.	6 min.
1	3.39*	45.54	12344	67	62.0	193	74.85	116	119	122	124	123	125
	.45**	5.64	6247	9.6	20.3	7.0	8.54	12.2	13.1	15.9	16.4	16.7	16.5
2	3.16	42.63	9413	71	47.0	194	74.71	122	125	131	133	131	133
	.37	5.01	4887	9.7	13.4	6.3	9.43	11.9	11.6	14.2	16.0	16.0	16.6
3	3.67	49.10	15927	61	80.2	191	75.02	110	112	111	115	114	116
	.38	4.18	5942	6.2	9.2	7.5	7.6	9.1	10.7	10.1	10.6	12.3	11.0
4	3.52	46.59	14691	64	68.0	192	75.82	114	116	118	121	119	120
								11.3					12.9

Sample	Recovery Heart-Rate, 600 kpm. 5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.5 min.	2 mins.	3 min.	4 min.	Recov. Rate 600 kpm.	Exercise Heart-Rate, 900 kpm. 1 min.	2 min.	3 min.	4 min.
1	119	107	100	93	89	86	86	85	85	35	135	141	144	148
	15.7	18.5	18.9	17.8	17.8	17.4	16.8	14.6	15.0	10.4	13.1	14.2	15.5	15.6
2	125	116	108	100	96	92	92	91	91	36	141	148	151	156
	16.7	16.8	19.4	19.0	17.2	17.8	16.0	13.7	15.0	10.1	13.4	14.6	15.8	14.9
3	110	97	91	86	81	79	78	79	77	34	129	134	136	139
	9.5	14,1	13.5	12.8	15.2	14.2	14.5	13.1	11.2	10.9	9.2	9.5	10.8	10.5
4	114	103	97	91	86	82	83	83	82	34	131	137	139	144
											9.2			

* Mean

** Standard Deviation

Sample	Recovery Rate Heavy Running		Time-Run	
1	39*	11.3**		
2	37	11.6	190	52.7
3	41	10.8	300	
4	39		261	50.9

Mean Values and Standard Deviations of Fitness Criterion Measures and Heart-Rates for Sample 1 (N = 40), Sample 2 (N = 22), Sample 3 (N = 18, and Sample 4 (N = 29) (Cont'd)

			Recovery Heart-Rate, 900 kpm.									Recov. Rate 900 kpm.
Sample	5 mins.	6 mins.	5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.5 mins.	2 mins.	3 mins.	4 mins.	
1	150*	152	146	134	122	112	109	104	99	99	96	43
	15.7**	15.9	17.1	19.1	20.1	20.5	20.8	19.1	19.2	15.3	16.5	8.9
2	157	158	152	141	129	121	117	111	106	105	104	41
	14.8	15.7	18.0	19.5	21.0	21.4	20.0	19.5	18.6	15.3	15.6	8.5
3	140	143	138	126	113	101	98	96	90	92	87	44
	11.6	11.7	12.6	15.0	14.5	12.9	16.9	14.9	16.0	12.2	13.1	9.2
4	145	147	141	130	117	108	105	101	96	97	94	42
		12.3			14.5							

	Recovery Heart-Rate, Heavy Run.						Recovery Heart-Rate, Heavy Running								
Sample	5 secs.	30 secs.	45 secs.	1 min.	1.5 mins.	2 mins.	5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.5 mins.	2 mins.	3 mins.	4 mins.
1	157	166	171	175	181	185	191	181	171	161	153	139	132	122	119
	14.8	12.0	9.5	9.1	8.1	8.5	8.1	9.4	10.2	14.4	14.6	16.7	14.6	14.0	14.1
2	163	171	175	179	185	190	193	183	173	164	157	143	136	126	124
	14.2	10.6	9.7	8.1	7.6	8.1	7.9	10.2	9.7	12.6	13.2	13.7	13.1	12.7	12.6
3	149	160	167	171	177	180	188	179	169	157	149	134	126	118	112
	11.9	10.9	7.0	8.3	6.1	5.9	7.7	8.2	10.6	15.8	15.5	18.7	16.0	14.5	18.6
4	155	164	170	174	179	183	190	180	170	160	152	137	130	121	117

* Mean

** Standard Deviation

APPENDIX E

CORRELATIONS BETWEEN HEART-RATES AND FITNESS CRITERION MEASURES

Correlations* Between Heart-Rates and Fitness Criterion Measures for Sample 1 (N = 40)

	Resting Heart-Rate	Exercise Heart-Rates: Light Work 1 min.	2 min.	3 min.	4 min.	5 min.	6 min.	Moderate Work 1 min.	2 min.	3 min.	4 min.	5 min.	6 min.
Maximal oxygen intake in litres/min.	-49	-51	-48	-59	-63	-61	-62	-58	-66	-70	-70	-66	-70
Maximal oxygen intake in mls/kg/min.	-25	-07	-08	-22	-24	-18	-18	-16	-22	-27	-27	-31	-31
Time-Run**	-15	-03	-14	-20	-21	-21	-18	-22	-23	-28	-20	-20	-24
The Johnson, Brouha, and Darling Fitness Index	-54	-47	-53	-63	-60	-56	-55	-53	-56	-58	-61	-59	-57
Work-done to Achieve Maximal Oxygen Intkae	-43	-40	-46	-59	-57	-61	-58	=56	-59	-63	-63	-58	-66
Body-weight	-31	-54	-50	-48	-50	-55	-56	-54	-57	-55	-56	-46	-51

	Exercise Heart-rates: Heavy Work (Running) 15 secs.	30 secs.	45 secs.	1 min.	1.5	2	Recovery Heart-Rates: Light Work 5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.5	2	3	4
Maximal Oxygen Intake in litres/min.	-34	-34	-32	-37	-41	-37	-60	-64	-56	-48	-49	-50	-47	-37	-53
Maximal Oxygen Intake in mls/kg/min.	-29	-32	-28	-34	-33	-32	-25	-31	-20	-13	-37	-21	-19	-13	-29
Time-Run**	-02	-16	-23	-33	-47	-40	-21	-12	-01	-05	-09	-07	-11	-08	-05
The Johnson, Brouha, and Darling Fitness Indes	-50	-59	-56	-61	-68	-69	-54	-60	-45	-44	-49	-44	-42	-37	-46
Work-done to Achieve Max. Oxygen Intake	-17	-21	-28	-27	-41	-42	-56	-53	-47	-45	-35	-42	-38	-32	-39
Body-weight	-11	-06	-06	-07	-11	-08	-47	-46	-48	-45	-21	-40	-40	-33	-36

Correlations* Between Heart-Rates and Fitness Criterion Measures for Sample 1 (N -40) (Cont'd)

	Recovery Heart-Rates													
	Moderate Work									Heavy Work (Running)				
	5 secs.	15 secs.	30 secs.	45 secs.	1 min.	1.5	2	3	4	5 secs.	15 secs.	30 secs.	45 secs.	1 min.
Maximal Oxygen Intake in litres/min.	-69	-62	-61	-66	-64	-57	-51	-44	-53	-26	-27	-23	-30	-30
Maximal Oxygen Intake in mls/kg/min.	-30	-33	-27	-43	-37	-30	-24	-19	-23	-22	-30	-25	-35	-37
Time-Run**	-31	-18	-18	-16	-14	-01	-00	-07	-02	-09	-03	-05	-15	-12
The Johnson, Brouha, and Darling Fitness Index	-54	-51	-52	-55	-55	-47	-51	-48	-51	-45	-37	-39	-43	-44
Work-Done to Reach Max. Oxygen Intake	-65	-55	-54	-52	-54	-43	-43	-33	-41	-16	-16	-11	-14	-13
Body-Weight	-50	-41	-45	-34	-38	-38	-38	-36	-41	-07	-00	-03	-00	-03

	Recovery Heart-Rates			Rate of Heart-Rate Recovery		
	Heavy Work (Running)			Light Work	Moderate Work	Heavy Work (Running)
	2	3	4			
Maximal Oxygen Intake in litres/min.	-32	-34	-44	-16	-25	-22
Maximal Oxygen Intake in mls/kg/min.	-28	-25	-25	-34	-30	-33
Time-Run**	-05	-18	-05	-14	-13	-18
The Johnson, Brouha and Darling Fitness Index	-53	-45	-55	-02	-26	-32
Work-Done to Achieve Maximal Oxygen Intake	-17	-14	-22	-32	-08	-10
Body-Weight	-08	-14	-27	-55	-02	-07

* Decimal points are omitted.
** Correlations for Sample (N = 22)

Levels of Significance: Sample 1 (N = 40), r =.33, sign. at 5% level. r = .42, sign. at 1% level. Sample 2 (N = 22) r = .41, sign. at 5% level. r = .53, sign. at 1% level.

APPENDIX F

INDIVIDUAL RECORD SHEETS

Name:	Age:	Wt.	Ht.
Address:	Smokes:		
Phone:			

Max. VO_2	I. Astrand.	Ast. Pred.	T.B.H.	M.S.C.		Resting HR.
Dates:						
R.Q.						

ASTRAND NOMOGRAM

Load kpm.	Pulse rates (after mins. of work) 1	2	3	4	5	6	7	8	9	10
900										
1200										

Prediction : L./min.

" : ml./Kg.B.W.

ASTRAND MAX VO_2 TEST.

Load kpm.	Exercise P.R. (mins.) Pre	1	2	3	4	5	6	Sub-M VO_2	Recovery P.R. 15s	30	45	1	1.30	2	3.0	4	5
600																	
900																	
1200																	
1500																	
1800																	
1950																	
2100																	

Max: L./min. ml./kg.B.W.

Work done at MaxVO_2: kpm. Max P.R.

JOHNSON-BROUHA RUN : Date / /

0	15	30	45	1	1.30	2	2.30	3	3.30	4	4.30	5

Max. P.R.:

15	30	45	1	1.30	2	2.30	3	3.30	4	4.30	5

Duration of run: secs.

1-1.30	2-2.30	3-3.30	PFI = 00 =
			2x

GAS ANALYSIS SHEET

300 KPM
600
900
1200
1500
1800
1950
2100

NAME _____

DATE _____

T = _____ °C
B.P. = _____ mm. Hg
Factor = _____

FeO_2 = _____ X $\frac{2.5}{1000}$ = _____ F_IO_2 = 20.94

FeO_2 = _____ (corr.) F_IO_2 = 00.03

$FeCO_2$ = _____ F_IN_2 = 79.03

FeN_2 = _____

V_EATPS = _____ l./min.

V_ESTPD = _____ X _____ = _____ l./min.

V_ISTPD = _____ X $\frac{\text{_____}}{.7903}$ = _____ l./min.

VO_2 = (_____ X .2094) - (_____ X _____) = _____l./min.

VO_2 = (_____ X _____) - (_____ X .0003) = _____l./min.

R.Q. = _____

Smoke _____ Number _____

Health (General) _____

Height _____ inches

Weight _____pounds _____ kilograms

Birthday _____

APPENDIX G

CORRECTIONS FOR THE BECKMAN E-2 OXYGEN ANALYSER AND THE AMERICAN METER CO. GAS METER

CORRECTIONS FOR THE BECKMAN E-2 OXYGEN ANALYZER

The accuracy of this instrument was tested against two micro-Scholander instruments operated by laboratory technicians in the Cardio-pulmonary Laboratory at the University of Alberta Hospital and the laboratory of the Department of Physiology at the University of Alberta.

The values obtained with the two Scholanders were averaged and a regression equation based on the Beckman reading and the Scholander values was calculated. This equation was found to be,

$$Y' = .893X + 2.22$$

where Y' = the corrected percentage of oxygen

and X = the percentage of oxygen as read on the Beckman E-2 analyzer.

The discrepancy was found to be due to impure nitrogen which was used as a calibration gas.

Based on the above regression equation, a second regression line was calculated which permitted direct correction of oxygen consumption values. This equation was found to be,

$$Y' = .871X + .0044$$

where Y' = corrected oxygen consumption in liters per minute

and X = oxygen consumption value obtained on the basis of the uncorrected percentage of oxygen as obtained on the Beckman analyzer.

After testing with the same Micro-Scholanders, the Godart Capnograph infra-red carbon dioxide analyzer was found to give accurate readings.

CORRECTIONS FOR AMERICAN METER CO. GAS METER #802

This meter was tested for its volume determinations using as standards the large Tissot tank in the Faculty of Physical Education Laboratory and a smaller Tissot in the Cardio-pulmonary Laboratory at the University Hospital. It was found to be recording volume readings in excess of actual volumes pumped, as indicated by the Tissot tanks. A second American Meter Co. gas meter, in use in the University Hospital, was found to give extremely accurate readings when compared to the same Tissot tanks.

The data collected was analyzed and a regression equation calculated. This equation was found to be,

$$Y = .22770 + .943099\ X$$

where Y = corrected volume

and X = volume as read on the American Meter Co. Gas Meter #802.

The regression equation was then used to calculate a complete set of correction tables. These tables also incorporated a factor for loss of volume during oxygen and carbon dioxide analysis, with the factor being considered as 300 c.c.

APPENDIX H

CALIBRATION OF INSTRUMENTS

AND ACCURACY OF CALIBRATION GASES

Calibration of Instruments and Accuracy of Calibration Gases

Treadmill. The elevation of the treadmill used in this experiment was checked by means of a Miracle Point Mercury Balance Model 10 Inclinometer which registered in degrees. The values were converted to a per cent scale by using a table of tangents.[1]

Bicycle Ergometer. The sinus balance was calibrated in the following manner:[2]

(a) The brake drum was removed and the mark on the pendulum weight was set at "0".

(b) A one kilogram weight was attached to the spring a shown in Figure 9. Weights were added or taken from the spring as required to bring the mark to the pendulum to the required scale mark of "1-kp".

(c) The process was continued through "2-kp", "3-kp" and so on up to "7-kp".

(d) If adjustment was required it was made by means of an adjusting screw which altered the center of gravity of the sinus balance.

American Volume Meter and Collins Centrifugal Pump. The rate of flow through the #802 American Meter Company Gasometer was checked by evacuating a known quantity of gas from a Collins Chain Compensated Gasometer with a capacity of 120 litres and a factor of 133.2 cc/min.

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[1] Campbell, J.W., Numerical Tables, Douglas Printing Co. Ltd., Edmonton, 1946.

[2] Astrand, P.O., Work Tests with the Bicycle Ergometer, AB Cyckelfabriken Monark, Varberg, pp. 1 - 14.

Calibration Gases for the Beckman E-2 Oxygen Analyzer and Godart Capnograph Carbondioxide Analyzer. The calibration gases used for calibrating the two instruments were evaluated several times by means of an analytical procedure outlined by Scholander[3]. The tests were carried out by the laboratory technician in the Department of Physiology and the Cardio-Pulmonary laboratory of the University of Alberta hospital.

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[3] Scholander, P.F., "Analyser for Accurate Estimation of Respiration Cases in One-half Centimeter Sample," Journal of Biological Chemistry," 167:235-250, 1947.